Sustainability metrics for the EU food system: a review across economic, environmental and social considerations

Deliverable No. 1.3

SUSFANS DELIVERABLES

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Based on the SUSFANS conceptual framework this paper describes the approach to metrics selection and the performance metrics that the SUSFANS team selected in consultation with its stakeholder core group for assessing the four key policy goals.

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SHORT SUMMARY FOR USE IN MEDIA

One of the main objectives of the SUSFANS project is to develop a set of concepts and tools to help policy and decision makers across Europe make sense of the outcomes and trends of the EU food system. This paper proposes a set of metrics for assessing the performance of the EU food system in delivering sustainable food and nutrition security. The performance metrics have been built up through the aggregation of a wide range of variables, which together help to monitor the achievement of four overarching policy goals for the EU food system, namely a balanced diet for EU citizens, reduced environmental impacts, competitive agri-food businesses and equitable outcomes of the food system. The project decided to take a hierarchical approach to aggregating from *Individual Variables* to *Derived Variables* to *Aggregate Indicators* to *Performance Metrics*. This approach aims at marrying the notion that decision makers want only a small but powerful set of metrics to communicate the findings of the assessment, with the need to substantiate these metrics with the best available data from a large number of sources in a transparent way. In this deliverable the current set up of the performance metrics focus on each individual policy goal. In a related report, the team explores if and how the performance metrics presented here can be quantified using available data and modelling tools, and which of the models of the SUSFANS tool box can estimate which ones of the performance metrics and how (report D1.4). In a final step the SUSFANS team will bring all performance metrics together in an integrated set that will allow a view across all four policy goals and thus across all aspects of sustainable food and nutrition security (forthcoming report D1.5). Further work is the quantification of metrics using case studies and prospective scenario analysis. In addition to their use for monitoring, the proposed metrics are geared towards quantification using selected computational modelling tools. As such, SUSFANS aims to assist in foresight on and the evaluation of transformative changes in the food system with rigour and consistency.

TEASER FOR SOCIAL MEDIA

A stakeholder-consultation based attempt to create better insight in and to unveil the complexity of food systems; the research project SUSFANS proposes a multi-layered index of sustainability metrics for the assessment of the EU food system, food security and dietary habits.

Twitter

Unveiling #foodsystems: building a holistic set of metrics to assess #food security in the EU food system based on stakeholder consultation

ABSTRACT

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

Based on the SUSFANS conceptual framework (D1.1), this paper describes the approach to metrics selection and the performance metrics that the SUSFANS team selected in consultation with its stakeholder core group for assessing the four key policy goals, namely 1) *a balanced and sufficient diet to EU citizens*; 2) *reduced environmental impacts*; 3) *competitive agri-businesses*; and 4) *equitable conditions and outcomes of the EU food system*. The project decided to take a hierarchical approach to aggregating from *Individual Variables* to *Derived Variables* to *Aggregate Indicators* to *Performance Metrics*. This approach aims at marrying the notion that decision makers want only a small but powerful set of metrics to communicate the findings of the assessment, with the need to substantiate these metrics with the best available data from a large number of sources in a transparent way. Thus the team selected between three to four performance metrics for each policy goal; the full list of performance metrics can be found in Table 11.

In this deliverable the current set up of the performance metrics focus on each individual policy goal. In a second step the SUSFANS team will bring all performance metrics together in an integrated set that will allow a view across all four policy goals and thus across all aspects of SFNS (D1.5). The team is also exploring which of the models of the SUSFANS tool box can estimate which ones of the performance metrics and how (D1.4).

1. INTRODUCTION

Assessing the status of the EU food system with respect to its Sustainable Food and Nutrition Security (SFNS) outcomes is not an easy undertaking due to the complexity inherent in the system. The difficulties already start with defining what SFNS is and what its outcomes are against which progress of the EU food system outcomes can and should be assessed.

The EU food system produces a wide range of outcomes, from a large variety of food products that have implications for the health and wellbeing of EU consumers, to environmental impacts such as land use change and GHG emissions, economic and social outcomes via the labour force working as farmers or in the food and drinks industry, and implications for global food security. All of these outcomes are assessed by different scientific communities and various policy goals for specific parts of the system as well as for the whole food system have been formulated. But the questions arise of how we know if we are making progress towards the formulated goals? And how can we assess the synergies and trade-offs across goals for the food system as a whole in implicit proposed innovations?

One of the main objectives of the SUSFANS project is to develop a set of concepts, metrics and tools that can help policy and decision makers across Europe make sense of the various trends and outcomes we see associated with the EU food system and to assess if the system as whole is making progress towards any of the goals that have been formulate for it by different communities. In its conceptual framework (D1.1) the project explored the concept of SFNS in more detail. Building on the traditional notion of FNS, SUSFANS has chosen to highlight the sustainability outcomes of a food system as well, leading to the notion SFNS. Departing from the concept of food and nutrition security as the only focus of assessing food system outcomes allows the combination of nutritional, environmental and (political) economic assessments and as such targeted policy action on multiple levels. The SUSFANS developed tool box can therefore be used to evaluate various policy measures and their unintended impacts across the whole EU food system, thus allowing for an assessment of synergies and trade-offs between and across policy goals.

For this work the project took a two-step approach (also see Rutten et al. (*Agricultural Systems 2016)*: As mentioned before, first a conceptual framework was developed that maps out the EU food system, its actors, driving forces, goals and outcomes and shows a number of feedback loops within the system (see report on deliverable D1.1). The framework thus serves as a roadmap for the selection of metrics and lays out what needs to be assessed. In a second step, the approach to metrics selection was developed, which is described in more detail in this report. Based on this approach the metrics for assessing the EU food system were selected and are described in this paper together with the basic ideas to bringing these together in an integrated set of metrics.

In section 2, this paper first gives an overview of other approaches to assess food and nutrition security and the sustainability aspects of the food system, which provided the background for the work done by the SUSFANS team. Section 3 describes the hierarchical approach the SUSFANS team took to derive from a wide set of variables a small set of performance metrics that describe the state of each of the four policy goals formulated for the EU food system by decision makers across the EU. The SUSFANS team refined these goals in consultation with the stakeholder core group as the main points for evaluating how the system currently fares but also for assessing how potential innovations to address these goals could have effects across the whole food system. As part of the consultation one of the goals was reformulated from addressing the impact that the EU food system has on the global food security to including also equity implications with respect to food system outcomes as well as related to the food system structure itself. Section 4 describes in detail the performance metrics and how they are derived from a set of indicators and variables for each of the four SUSFANS policy goals, namely, 'A sufficient and balanced diet for EU citizens', 'Reduced environmental impacts of the EU food system', 'Competitiveness of the EU agri-food business', and 'Equity outcomes and conditions of the EU food system'. Section 5 then provides an overview of the full set of metrics SUSFANS selected to assess the status of SFNS in EU food system and a description of some open questions that the research up to date revealed. The section ends with an outlook of how the complete set of performance metrics can be used in an integrated manner, which will be described in more detail in deliverable D1.5.

2. SUSTAINABLE FOOD AND NUTRITION SECURITY – A REVIEW OF THE RELEVANT LITERATURE

The conceptual framework of SUSFANS builds on previous work around food systems and food and nutrition security (FNS). The selection of metrics to assess food and nutrition security in the context of the EU food system is based on the framework in that it sets out the basic elements that could be assessed.

In this section, we review some of the earlier work to assess food and nutrition security with a particular focus on approaches that aim to assess also the sustainability aspects of FNS as this is the key focus of the SUSFANS project and framework. Within the SUSFANS work these include in addition to the nutritional outcomes of the food system also its environmental, social and economic consequences, both for the actors within the system (i.e. primary producers and food chain actors) as well as outside of it.

2.1 Food systems outcomes

An increasing number of approaches to assess food systems are being developed, many aiming to provide tools to address food insecurity or climate change. What is common in the majority of these earlier approaches, is their emphasis on the need for a holistic and systematic interrogation of food systems. As such, as clear shift has been made from a focus on solely food production, to one that also incorporates food consumption, retail and policy (CFS 2012, Acharya, Fanzo et al. 2014, Allen and Prosperi 2014, Maggio, Van Cricking et al. 2015, Le Vallée and Grant 2016). A food systems approach is "being seen as the most effective strategy to enhance nutrition security in a more sustainable manner" (Gustafson, Gutman et al. 2016, p. 2) for a number of reasons. Besides providing a framework to structure the debate of a highly complex issue, it allows for an integrated assessment that can focus on impacts and leverage points in the different domains of the food system (Ingram 2011). As also underlined in D1.1 (Zurek et al. 2016), this has motivated SUSFANS in taking a food systems approach. Where food systems approaches tend to differ, is in their framing of the outcome of the system. Within food systems research this is something that is still debated, as many different definitions are used to describe food systems outcomes. This is essential to note, as these outcomes are embedded in certain scientific disciplines and embedded in discourses around food systems.

Throughout the literature diverse terms can be found, such as: food security; nutrition security; food and nutrition security; food sovereignty; sustainable nutrition security; and sustainable diets[1]. Taking position in the debate on food systems outcome signals a particular discourse and way of understanding the food system. Broadly speaking, three discourses have been influential in the field of food research. The first, *food security*, was articulated in order to apply at a national and global scale, allowing for a systematic and economic assessment of food supply (Clapp 2014). Initially it focussed heavily on availability and

[1] In D1.1 (Zurek et al. 2016 p. 5) a detailed overview of the historical development and use of these terms was presented.

adequacy, and was as such prone to an economic and production oriented debate. But as this was later complemented by the work of Amartya Sen (1981), who emphasised the aspect of access, it allowed for a more political economic review of food supply. For analytical purposes, it was broken down into the more commonly known aspects of accessibility, availability, stability and utilisation of food (Pinstrup-andersen 2009, Pangaribowo, Gerber et al. 2013). *Nutrition security*, the second commonly used discourse, emphasises the importance of nutrition and health within food security and underscores the potential of 'nutrition planning' (Acharya, Fanzo et al. 2014, Gustafson, Gutman et al. 2016). It departs from the notion of food security, but adds a more technical layer by stressing that the four aspects of food security do not guarantee micronutrient security. This line of thinking focusses more on utilization of food in an individual's body (SUN 2010). Acknowledging the importance of both perspectives and especially the integration of the associated practices, these two were later merged into the notion of *food and nutrition security* (CFS 2012, Pangaribowo, Gerber et al. 2013, Prosperi, Allen et al. 2014). This definition is useful since it can be applied at many levels, from the micro-level to the global level. The third perspective that has been gaining momentum and as such is certainly worth mentioning is that of *food sovereignty*. This term was initially championed by the social movement La Via Campesina and stressed that food sovereignty was above all a 'precondition to genuine food security'. Contrary to the earlier notions, food sovereignty is more a political agenda aiming to further social and environmental just food systems. This rights-based approach to agriculture and food sets out to empower and encourage peasants around the world to mobilize politically (Clapp 2014).

Over the last decade, an increasing awareness of the impacts of climate change on food systems and vice versa, have sparked the incorporation of notions of environmental sustainability within these discourses (Allen, Prosperi et al. 2014). Connecting food system's outcomes to environmental protection has further underscored the need for a systems perspective and has led to changing and adaptation of the initial discourses, such as: *Sustainable nutrition security*, which remains focussed on nutritional content of food but emphasises the system of nutrients need to be environmentally sustainable. An also relatively new framing is the notion of *sustainable diets*, which is increasingly used in reporting (Allen and Prosperi 2014, Fischer and Garnett 2016, Lukas, Rohn et al. 2016, Ranganathan, Vennard et al. 2016). Although it links to the environmental impact of the food system, its main focus is more on the actual diet than the food system.

Based on the earlier use of food systems discourses and the aim of the SUSFANS conceptual framework to create an enhanced understanding of the food system, the novel lens of *sustainable food and nutrition security* (SFNS) is put forward to describe the outcome of food systems. Departing from the concept of food and nutrition security allows the combination of nutritional and (political) economic assessment and as such targeted policy action on multiple levels. Building on this notion, SUSFANS has chosen to highlight the sustainability component by making it a central element of the analysis, leading to the notion SFNS.

Table 1 Overview of recently developed tools to measure food systems' outcomes

Article organisation	Used frame	Policy goals[2]	Indicators/ metrics	Focus of approach
Pangaribowo et al. (2013) FOODSECURE	Food and Nutrition Security	1, 4	8 metrics	Combines existing indicators around FNS
Le Vallée and Grant (2016) Canada's Food Report card	Food performance	1, 2, 3	5 metrics, 43 indicators	Food systems; business oriented; comparison OECD countries
Gustafson et al. (2016)	Sustainable Nutrition Security	1, 2, 4	7 metrics with underlying indicators	Food systems; National level analysis
Acharya et al. (2014) CIMSANS	Sustainable Nutrition Security	1, 2, 3, 4	7 metrics	Food systems; holistic
Allen and Prosperi (2014) Bioversity international	Sustainable diets	1, 2, 4	8 indicators	Food systems; outcomes and drivers
Prosperi et al. (2014)	Food and Nutrition Security	1, 2, 4	-	Food systems; Mediterranean, vulnerability
Lukas et al. (2016)	Sustainable diets	1, 2	4 health and 4 environ. metrics	Nutritional footprint of meal; Offers a tool for consumers
Ballard et al. (2013) FAO	Food security	4	8 indicators at household level	Adaptation of earlier food insecurity metrics towards experience-based monitoring
Zamudio et al. (2014) IISD	Food security	1, 3, 4	5 metrics with underlying indicators	'Local' Food systems' resilience indicators

There have only been few attempts to explore SFNS (see table 1). The discussion around food and nutrition security has slowly been advancing in this direction, but so far only few integrated sets of metrics have been developed. SUSFANS aims to add to this body of work with a holistic set of metrics that give a

[2] SUSFANS policy goals: 1) a balanced, healthy diet to consumers; 2) reduced environmental impacts; 3) competitive agri-businesses; and 4) equitable outcomes and conditions of the EU food system

comprehensive overview of the food system. This builds on the work of Prosperi et al. (2014), Gustafson et al. (2016), Acharya et al. (2014) and the 'traditional' food security indicators (Pinstrup-andersen 2009). Gustafson et al. (2016) have developed a comprehensive and holistic model of food systems at national level. This consists of 7 metrics selected by experts, with underlying indicators, ranging from ecosystem stability, to nutrient adequacy and sociocultural wellbeing. They argue that a focus on these indicators allows for the shaping of pathways to more resilient food systems. In the work of CIMSANS (Acharya et al. 2014) a similar approach is wielded, as they have developed metrics to assess the main activities within the food system, with a focus on sustainable nutrition security. These metrics were similarly selected through expert-consultation. Lastly, although Prosperi et al. (2014) do a vulnerability assessment of the Mediterranean food system, they do highlight four goals as being central to sustainability and FNS: human health and nutrition; cultural acceptability; economic viability; environmental protection. As described, all three studies take a holistic approach to the food system and have certain focus areas that cover both sustainability and FNS.

However, the in SUSFANS chosen frame of SFNS allows for an approach that favours both micro-level impacts and global impacts and combines nutrition and health to environmental, economic and social outcomes. Such a viewpoint connects to the four broader EU policy goals for food systems: 1) deliver a balanced, healthy diet to consumers; 2) reduce its negative environmental impacts; 3) be built on competitive and socially balanced agri-businesses; and 4) contribute to global food security and further equity considerations within the food system and with respect to its outcomes. This is essential to SUSFANS's aim to create a tool that will aid policy-makers in their decision-making around food systems issues. Use of other framings of food systems' outcomes does not allow a similar connection to the EU policy goals; e.g. sustainable diets as a frame does not connect to agri-business aspects (see table 1). As such, one of the key novelties of the SUSFANS approach is the interconnection of environmental, business competitiveness and social/equity indicators with food and nutrition security indicators. Especially the latter – social equity - is particularly challenging, since this has not yet been attempted in relation to the food system. A second contribution is the extensive build-up of robust metrics, by using various layers. While a common approach is to have indicators lead to a metric, SUSFANS has multiple layers, as this allows for the operationalization of the EU policy goals. How this is approached and consequently built up within SUSFANS will be described in detail in chapter 3. In the next section we briefly describe what differs in the process of developing the metrics.

2.2 Stakeholder engagement in metrics selection

There is an urgent need for the development of improved metrics and data for the assessment of the "food environment" in order to better inform policy-makers (Global Panel 2015). The purpose of the SUSFANS tool will be to give insight into what certain policies might change in terms of food systems components. Indicators and metrics are regarded as useful information tools, able to indicate the state of a certain policy goal. Through the use of indicators and metrics, both systems complexity as well as data can be made understandable outside their research discipline (Gustafson, Gutman et al. 2016, Lehtonen, Sébastien et al. 2016). As such they have the potential to create awareness, teach lessons, function as evaluation tools and improve transparency and (policy) measures (Gudmundsson 2003, Rosenström and Lyytimäki 2006, Lehtonen 2015). Indicators can range from descriptive, meaning pure data, to aggregated indicators, meaning built-up out of several indicators. As such, they can communicate "a given situation or underlying reality which is difficult to quantify directly" (Pangaribowo, Gerber et al. 2013, p 15).

However, Lehtonen et al. (2016) provide a more critical view on the use of indicators and metrics, as they argue they can easily be turned into a political tool and as such misused. Although indicators are able to communicate complex themes to policy makers, they are a certain discursive portrayal of a situation or reality and as such not 'neutral'. Researchers' assumptions about underlying conceptual frameworks to indicators often remain hidden to policymakers. When there is no transparency on their underlying causal relations, indicators can become tools of control to those who are already power, rather than empower all stakeholders. Connecting to this, is the critique on expert-led construction of metrics, which closes down processes and does not allow input from other stakeholders (Lehtonen 2015, Lehtonen, Sébastien et al. 2016). SUSFANS aims to address the first critique through the development of an online tool that allows browsing through the underlying causal relations and justifications. As such the tool aims to empower stakeholders that use it, by being transparent about the underlying assumptions. Secondly, by opening the space for stakeholders to participate in the development of metrics and comment on causal relations, SUSFANS aims to increase reflexivity and be responsive to stakeholder input. For this the metric selection has been discussed in two stakeholder core group meetings and another round of consultations is planned in the next months before finalizing the integrated tool for the SUSFANS metrics (see sec 5) to make the tool user friendly and give stakeholders the opportunity to review the current set of metrics one more time.

3. THE SUSFANS APPROACH TO SELECTING METRICS FOR ASSESSING SUSTAINABLE FOOD AND NUTRITION SECURITY OF THE EU

In order to develop a meaningful set of metrics to assess the performance of the EU food system with respect to SFNS outcomes the SUSFANS team decided to use the four policy goals for the EU food system as laid out in the SUSFANS conceptual framework (D1.1) as the starting point. These goals have been formulated in various policy fora across the EU and its member states and were discussed in two workshops with the project's stakeholder core group. They state that in order to achieve SFNS the EU food system should deliver, 'A sufficient and balanced diet for EU citizens' and 'Reduced environmental impacts of the EU food system', foster the 'Competitiveness of the EU agri-food business', and take into consideration 'Equity outcomes and conditions of the EU food system'.

In this section, we build on D1.2 and describe the approach that was taken to derive a small set of performance metrics for each policy goal that can give decision makers a quick overview about the direction in which the food system is heading and if innovations introduced to the system result in the desired change towards more SFNS outcomes, i.e. if progress towards achieving one or all of the policy goals is made. With these performance metrics the SUSFANS team aims to answer to stakeholder requests for a small number metrics that are easy to understand and to communicate. Each of the performance metrics is derived from a much larger set of indicators and variables that describe the EU food system in more detail. After explaining the specific terms used by the SUSFANS project and the hierarchical approach that was developed to connect variables to performance metrics the section ends with a description of the basic aggregation pathway from variables to indicators to performance metrics. In D4.7, the SUSFANS team already run a first test application of the approach to metrics aggregation described here. The test will be repeated for the three other policy goals in the next few months.

3.1 Definitions of used terms

The SUSFANS project decided to use four different terms to define the data and metrics used by the project. These are *Individual Variable*, *Derived Variable*, *Aggregate Indicator* and *Performance Metric*. As there are many different definitions of these terms, the project defined these in more detail for its own purpose. The definitions are:

- **Individual Variable**: a measure that can be counted and/or quantified against a universally agreed upon standard (e.g. hectares, kg), usually a measure that can be quantified and/or counted.
- **Derived Variable**: Combines a number of individual variables to come up with a new measure (e.g. Ratio of energy intake vs expenditure, N input vs. output) in some cases additional information is used to derive the variable (e.g. conversion of GHG emissions to total CO2eq).
- **Aggregate Indicator**: Combines one or various derived variables and evaluates them against an objective (e.g. reduction of N surplus, marine biological diversity, food access).
- **Performance metric**: Combines various aggregated indicators and assesses them against achievement of EU targets/goals (e.g. balanced diet for EU citizens, climate stabilization)

Project members felt that these distinctions were needed to be able to find the appropriate data for the assessment of EU FNS, describe the specific levels of aggregation and the relationships between data and describe in a transparent way how existing and newly generated data can be used to develop a small set of performance metrics that are needed to communicate the findings of the assessment to EU policy and decision makers.

3.2 The hierarchical approach to metrics selection

The relationships between the different types of data and how they can be aggregated into a coherent set of communicable metrics to assess EU FNS are described in the Hierarchical Approach developed by the project. Figure 1 gives a summary of the approach.

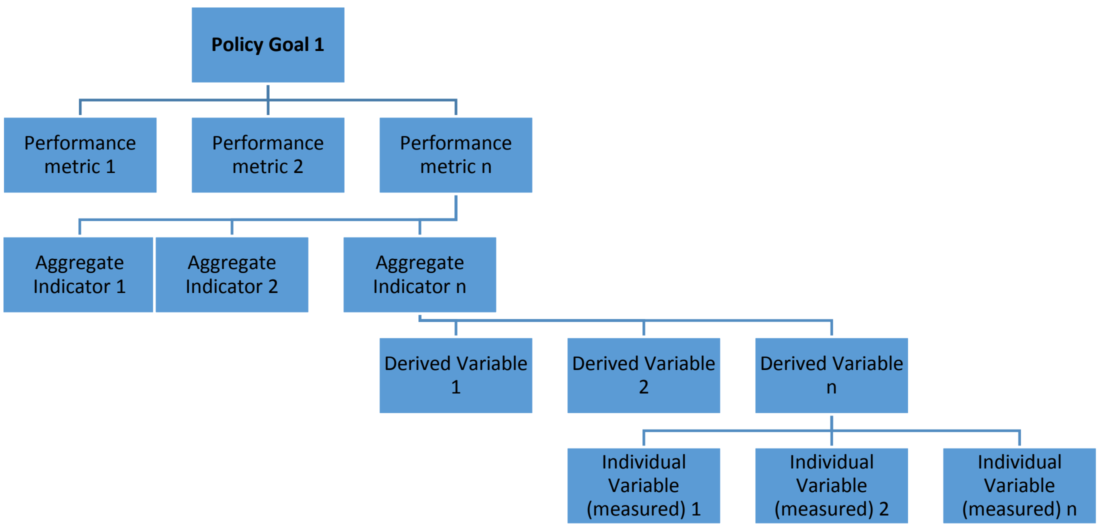

Figure 1 The hierarchical approach taken by the SUSFANS project to develop metrics to assess SFNS in the EU

The hierarchical approach aims at marrying the notion that decision makers want only a small but powerful set of metrics to communicate the findings of the assessment, as it was expressed by stakeholders in the meeting held with them in October 2015 (see meeting report), with the need to substantiate these metrics with the best available data from a large number of sources in a transparent way. Thus the project started to develop the approach beginning with the four policy goals described in the SUSFANS conceptual framework. For each of these goals two to three Performance Metrics were defined that could show the status of the EU and/or Member state food systems with respect to each goal (for a mechanism to look across all four goals see Section 5). Each of the Performance Metrics result from the aggregation of a large number of data or individual variables into a set of derived variables. These derived variable in turn are then aggregated up to an Aggregate Indicator, which in turn are brought together to describe a Performance Metric for a specific policy goal.

3.3 The basic aggregation pathway - from variables to performance metrics

In this section the principles the SUSFANS team applies to aggregating from variables up to performance metrics are explained.

The **Policy goals** point to overarching societal challenges within the EU food system that policy and decision makers need to address in order to achieve SFNS. Each policy goal is composed of various *'areas of concern'* for which society wants to improve the situation. This is measured with **performance metrics**, which indicate how far society has come at one point in time for reaching the desired endpoint of development against a reference point in time.

The performance metrics themselves are composed of one or more specific **policy visions** which describe in more detail how a particular area of concern should be resolved (e.g. area of concern: biodiversity loss, policy vision: halt loss of biodiversity). Policy visions are linked to a certain time frame and link to measureable data.

Aggregate variables[3] V_g combine one or various derived variables to the level of the policy visions g. They are measured (or transformed) to the same unit as the policy targets which quantify the policy visions. **Policy targets** V_g^t for a policy vision are linked to a certain point in time t_1 and might be different for different countries or at EU level. An example of a policy target is the level of

[3] Aggregate variables are 'new' and have not been introduced before. Basically the definition of 'aggregate indicator' is split into two steps: first aggregation to aggregate variables and then evaluation against objectives to aggregate indicator.

GHG emissions for a country in a target year t_1. Both the V_g and T_g for the target year t_1 (predicted by models) are compared to the situation of the aggregate variable V_g^R in the reference period t_0 (e.g. present).

Aggregate indicators I_g evaluate aggregate variables with respect to how much of the path that needs to be gone from the reference V_g^R to the level of desired level of the policy vision V_g^G is already achieved. The name of the aggregate indicators is usually a 'reduction of a gap to optimum or an undesired fact (e.g. emissions)'

$$I_g = \frac{V_g - V_g^R}{V_g^G - V_g^R}$$

The aggregate indicator can also be calculated for the policy target:

$$I_g^t = \frac{V_g^t - V_g^R}{V_g^G - V_g^R}$$

I_g can assume values between zero and one if there is an 'improvement' towards reaching the policy vision, but it can also be negative if the situation is worsened.

I_g^t can assume values between zero and one. Thereby, the higher I_g^t the more ambitious are the policy targets. It could be interpreted such that in such case the policy vision is judged to be more urgent as compared to policy target with a lower I_g^t. Only in very rare cases it is possible that I_g^t assumes values >1, for instance if a world with zero emissions is ideal, but a world with 'negative' emissions is possible.

Performance metrics aggregate Aggregate Indicators into a meaningful number that shows how well the 'scenario' performed for each of the dimensions defined for the overarching policy goals. To do the aggregation, weighting factors w must be defined for each policy vision within one of the dimensions (=> performance metrics). Those weighting factors usually are 1 unless the predominance of one policy vision over the others can be justified. Weighting factors can be different from one to consider correlations between policy goals. For instance, the policy area 'nutrient surplus' is overlapping with the policy area 'air and water pollution' and 'GHG emissions' and thus has a weighting factor of zero to avoid double counting.

$$M = \frac{\sum_g \{I_g \cdot w_g\}}{\sum_g \{w_g\}}$$

In analogy, the policy targets can be aggregated to the same dimensions:

$$M^t = \frac{\sum_g \{I_g^t \cdot w_g\}}{\sum_g \{w_g\}}$$

Aggregation of the performance metrics to the policy visions can be done in many ways and it `could be the use of the target metrics M^t as a proxy for importance, based on the following reasoning:

The more important a dimension of a policy vision is considered, the higher the level of ambition is sought for setting the targets, thus the targets are closer to the policy vision and the higher the score of M^t.

Thus one option to calculate the overall score for the policy goal could be summing up over all performance metrics *m*:

$$S = \frac{\sum_m \{M^t \cdot M\}}{\sum_m \{M^t\}}$$

More details for estimating the various performance metrics will be given in D1.4 which describes the modelling strategy the SUSFANS team will employ to estimate the selected metrics.

4. METRICS TO ASSESS THE STATUS OF SUSTAINABLE FOOD AND NUTRITION SECURITY IN THE EU CONTEXT

The EU food system provides various outcomes to EU citizens and also influences the food security status of people outside the EU. EU policy and decision makers formulated various goals with respect to these outcomes which the SUSFANS project distilled into four policy goals (for details see the SUSFANS conceptual framework, D1.1). In order to assess if and how potential changes that could be introduced to the food system would influence the outcomes the project developed a set of performance metrics that will allow to monitor system performance. In this section we describe the performance metrics together with the indicators and variables that the project will collect to construct the performance metrics according to the approach described in section 3. It should be noted here that the approach taken to selecting the metrics started on the conceptual side, thinking of the ideal metrics, irrespective of if the SUSFANS modelling tools could model all of the metrics. The metrics were also discussed with the stakeholder core group (SCG) of the project in two workshops and the SCG members could review the different stages of metrics development. The exception are the metrics for the Equity goal (see section 4.4) as this policy goal was developed based on SCG requests after the second workshop (Oct 2016). In this goal the original ideas to capture the impact of the EU on global food security were enlarged to include equity considerations for EU food system conditions and outcomes.

4.1 Policy goal: Balanced and sufficient diets for EU citizens

Food and nutrition security 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). At the EU-level, this definition is taken to include the simultaneous challenges of under-nutrition and over-consumption – the "double burden of malnutrition" – as well as the heterogeneity across socioeconomic and demographic strata and regions in terms of food utilization and food access. Balanced and sufficient diets are determined by their contribution of energy, macronutrients and micronutrients to total daily body needs.

Balanced and sufficient diets do not only address the quantity of a diet, but also the quality. Diets should provide foods and nutrients to prevent deficiencies, and reduce the risk on chronic diseases, and at the same time address the increasing burden of overweight and obesity. Performance metric of balanced and sufficient diets should therefore, include metrics to assess the energy balance (quantity) as well as nutrient adequacy (quality), including the contribution to the dietary quality of foods groups and nutrients that should be increased, as well as food groups and nutrients that should be reduced.

In SUSFANS we use a two-part approach to assess the nutritional adequacy of the diets. First, we use food-based dietary guidelines to address inadequacies in diets. Food-based dietary guidelines provide a basic framework on the average amount of foods that individuals within a population should be eating in terms of foods instead of nutrients, while still aiming at supporting desirable food and nutrient intakes to promote overall health and prevent chronic diseases. Second, a selection of nutrients (e.g., calcium, iron, zinc, vitamins) that are of concern in specific subpopulation and regions of the EU, and nutrients with adverse effects on health (e.g., saturated fats, salt, added sugar) will be added. The dietary assessment data that will be used in SUSFANS are well-suited for an EU-wide assessment of nutritional quality of the EU diets. These individual level food consumption data will allow us to assess the intake of foods and food groups and simultaneously assess the intake of nutrients. These analyses will be further stratified to account for educational level (related to social economic status), sex, and age categories when appropriate. We defined three performance metrics (PM) for balanced and sufficient diets: a metric based on **(1) food-based dietary guidelines**, a metric based on **(2) nutrient recommendations**, and a metric on **(3) energy balance**.

Dietary assessment method

To assess individual dietary intake in SUSFANS we made use of consumption data derived from national dietary surveys between 2003-2008, which are nationally representative population samples, from four different countries (Czech Republic, Denmark, France and Italy). These countries represent the different regions in Europe (North, East, South and West) and account for ~30% of the European population.

In contrast to national-level estimates of food availability, e.g., food balance sheets, from the UN Food and Agricultural Organization (FAO), dietary surveys are capable of assessing within-country differences across key population subgroups, e.g., by age or sex, and assess population distributions of intake (Vandevijvere, 2013).

For every survey we obtained and assessed information about the survey methods and population characteristics. In the Czech Republic dietary intake was assessed by two 24-hour dietary recalls, and in Denmark, Italy and France, by diet records. Recalls and records were spread equally over all days of the week and seasons. For this project two randomly selected non-consecutive days in all 4 countries were included for data analysis. To calculate nutrient content of the diets, consumption data were linked to national food composition databases, and averaged over two days.

Due to intra-individual variability, a single or duplicate 24h recall does not represent the usual individual intake, but it characterizes the average intake of a group or population fairly well. Population distributions will be wider than the usual intake, especially for foods that are irregularly consumed, such as fish. For example, if persons have zero consumption on both assessment days, these persons could still be consumers. The non-consumption at population level can be assessed only after application of methods to calculate usual-intake distribution, applying e.g. the Nusser method. This would require the administration of a Food Propensity Questionnaire (EFSA, 2014; Tooze, 2006). However, to describe the diet quality of a population, the average intake based on two assessment days gives an appropriate estimate that we can use.

An overview of the balanced diet metrics can be found in Table 4.

4.1.1 Performance metric 1: Food based dietary guidelines

The first performance metric for balanced and sufficient diets is positioned around foods-based dietary guidelines, which may be regarded as a holistic approach that provide advice on foods, food groups and dietary patterns to promote overall health and prevent chronic diseases. The food-based approach was primarily chosen because increasing evidence points out that specific foods and dietary patterns have a substantial role in the prevention of chronic diseases (Mozaffarian, 2010). Because food-based dietary guidelines are usually defined at the national level, differences exist across Europe. We therefore first established a common set of food-based dietary guidelines that align food choices of European population groups (Table 2).

Individual variables 'intake of foods products'

Individual variables are the mean intake of food products (g/d). We made use of the FoodEx2 exposure hierarchy from the European Food Safety Authority (EFSA) to consistently classify the food consumption data obtained from national food consumption surveys. Improvements may be proposed at a later stage, based on in depth-analyses of country-specific data.

Derived variables 'Adherence to the guidelines for food groups.'

All these individual food products are aggregated into food groups that are aligned with the food based dietary guidelines (see protocol 2.2 SUSFANS). Several food groups are classified as 'healthy' food groups, e.g., foods that require a minimum intake (vegetables, legumes, nuts and seeds, fruits, fish, dairy) and, some food groups are classified as 'unhealthy' food items, e.g., foods for which a maximum intake is recommended (red- and processed meat, hard cheese, sugar sweetened beverages, alcohol and salt). For each of these derived variables, individual goals, e.g. per food groups, were set to be able to calculate the population adherence to these individual food groups (Table 1).

Table 2. Food-based dietary guidelines used in SUSFANS

Food	Guideline
Vegetables	≥200 g/d
Legumes	≥150 g/week
(Unsalted) nuts and seeds	≥15 g/d
Fruits	≥200 g/d
Fish	≥150 g/week
Dairy	≥300 g/d
Red/ processed meat	≤500 g/week
Hard cheese	≤150 g/week
Sugar sweetened beverages	≤500 mL/week

Alcohol	≤10 g/d
Salt	≤6 g/d

Source: Report SUSFANS D2.2 (2016)

The percentage of persons that adhere to these goals is based, not only on the average consumption within a population, but also on the distribution of that population. In general adherence to individual guidelines is expected to be low. We evaluated dietary intakes adjusted to a 2000 kcal per day diet to assess diet quality independently of diet quantity, and to reduce measurement error within and across surveys (Willett, 2012).

Performance metric

To derive a performance metric, we constructed a score for the overall dietary pattern we selected 5 key foods (fruits, vegetables, fish, red- and processed meat, and sugar sweetened beverages). Intake of foods, rather than macronutrients or micronutrients, may be most relevant for non-communicable disease risk (Micha, 2015). Foods and food groups that are mostly included (on different aggregation levels) in dietary quality indices are fruits, vegetables, staple foods, sugar, dairy products, and protein sources such as meat, eggs and plant based proteins (Trijsburg, not published). The Global Burden of Diseases Nutrition and Diseases Expert Group published their rational to include a selection of foods related to non-communicable diseases (Micha, 2015). They included fruit and vegetable intake as these are associated with reduced risks in CHD, stroke, oesophageal cancer and lung cancer. Fish intake was included because it reduced the risks of CHD and stroke. Red and processed meat intake were selected because these are related to increased risk of CHD, diabetes and colorectal cancer. Sugar sweetened beverages were included due to their relation with increased risks diabetes and increase in BMI (Micha, 2012). They also included nuts and seeds and whole grains in their list of key foods. However, we excluded those as nuts and seeds are often eaten salted, and with the current assessment method we could not distinguish between salted and unsalted nuts. Furthermore, we did not include whole grain products as these are difficult to classify and compare between countries. However, if assessment methods will improve in the future and can quantify whole grain consumption better, we advise to include whole grain intake in this diet quality index. For now, dietary fibre intake, which is highly correlated with whole grain intake will be included in the nutrient based performance metric. Finally, we did not include milk as it is highly correlated with calcium intake, which will be included in the nutrient based performance metric as well.

To derive a summary score for the five key foods, we used previously set cut-offs for each food item. Capping of intake (defined as food intake is equal to cut-off value if intake exceeded the cut-off value) will be applied to avoid crediting of overconsumption (Drewnowski, 2009), and also vice versa for foods that should be limited. First, the scores will be calculated for each individual. Subsequently, these individual scores will be averaged to calculated the population mean. A continuous score between 0 and 10 points will be calculated based on the average intake of two assessment days. Similar to the Healthy Eating Index, the five indicators are weighted equally (1/5) in the total score.

We calculated the scores based on the five indicators (Table 3) with the following formulas:

- If vegetable intake ≥ 200 g then score is 10; if<200 g then score is g vegetable/200*10
- If fruit intake ≥ 200 g then score is 10; if<200 g then score is g fruit/200*10
- If fish intake ≥ 20 g then score is 10; if<20 g then score is g fish/20*10
- If meat intake ≤ 70 g then score is 10; if>70 g then score is 70/g meat*10
- If sugar sweetened beverage (SSB) intake ≤ 70 g then score is 10; if>70 g then score is 70/g SSB*10

Table 3. Dietary quality score foods: five selected food items standardised for 2000 kcal/d.

	Components	Guidelines Healthy diet	Maximum score (=10)	Calculation score
1.	Vegetables	Eat at least 200 g/d	≥ 200 g	g/200*10
2.	Fruit	Eat at least 200 g/d	≥ 200 g	g/200*10
3	Fish	Eat at least 150 g/week	≥ 21.4 g	g/21.4*10
4.	Red and processed meat	Eat at most 500 g/week	≤ 71.4g	71.4/g*10
5.	Sugar sweetened beverages	Drink at most 500 mL/week	≤ 71.4g	71.4/g*10

For example, consumption of 100 g/d of fruits (standardized to 2000 kcal/d) will give a score of ‘5’ for the component ‘Fruits’. Eating more than the recommended intake for fruits, vegetable, and fish will not give a higher score. Each component has a maximum score of 10 points. Scores for each food item will be summed up and multiplied by 2 to derive at a total score with a maximum of 100. A score of ‘100’ represents complete adherence to the food-based dietary guidelines that are included.

This food based performance metric can be used for total populations, e.g. national surveys, but also for population subgroups. National surveys consist of individual based data that include also several demographic characteristics. These can be used to stratify the population according subgroups (age, sex, BMI, educational level).

4.1.2 Performance metric 2: Nutrient recommendations

The second performance metric for balanced and sufficient diets is positioned around on nutrient-based recommendations. Food-based dietary guidelines cover a wide range of foods and thus nutrients, however, some nutrients might become "of concern", i.e. are critical nutrients that are not clearly reflected in the food-based dietary guidelines, and are relevant for public health. Especially, when shifting from an animal-based dietary pattern towards a more plant-based dietary pattern some nutrients may not clearly be reflected in the food-based dietary guidelines.

Individual variables 'intake of nutrients'

Individual variables are the mean intake (µg/d, mg/d, g/d) of nutrients for which a minimum intake (protein, vitamins and minerals) is recommended and, mean intake of nutrients for which a maximum intake should not be exceeded (saturated fats, added sugars, sodium). Similar to the foods, we will evaluate nutrient intakes adjusted to a 2000 kcal/d diet.

Derived variables 'Adherence to the DRVs for individual nutrients.'

For each of the nutrients the percentage of the population that complies with the dietary recommended values (DRVs) will be calculated, without correction for within subject variability. DRVs are defined using reference values from European Food Safety Authority (EFSA, 2010), either average requirement (AR) or adequate intake (AI) if requirement has not been set, and maximum recommended values (MRV) using reference values of the World Health Organisation (WHO, 2003; 2012; 2014). DRVs and MRVs are summarized in SUSFANS protocol 2.2.

Performance metric

To evaluate European populations' nutrient intakes, the nutrient density of the diet was quantified using a Nutrient Rich Diet (NRD) score (van Kernebeek, 2014; Roos 2015) based on the principles of the Nutrient Rich Food Index (Drewnowski, 2009; Fulgoni, 2009). The NRD algorithm was calculated as:

$$NRD\ X.Y = \sum_{i}^{i=X} \frac{Nutrient\ i}{DRV\ i} x100 - \sum_{j}^{j=Y} \frac{Nutrient\ j}{MRV\ j} x100$$

where X is the number of qualifying nutrients, Y is the number of disqualifying nutrients, nutrient i or j is the average daily intake of nutrient i or j, DRV is the Dietary Reference Value of qualifying nutrient i and MRV j is the Maximum Recommended Value of the nutrient to limit j.

For the present analyses we use the NRD9.3 and the NRD15.3. The NRD9.3 includes nine nutrients to encourage (protein, dietary fibre, calcium, iron, potassium, magnesium, and vitamin A, C and E) and three nutrients to limit (saturated fat, added sugar, and sodium) and will be calculated per 2,000 kcal and capped at 100% DRV. It was primarily chosen based on validation results among US populations (Drewnowski, 2009; Fulgoni, 2009). To capture more nutrients that are potentially relevant for EU populations we also used the extended version, e.g., the NRD15.3 that additionally includes mono-unsaturated fatty acids, zinc, vitamin D and B-vitamins (B1, B2, B12, folate), but excluding magnesium.

The NRD9.3 score can range from 0-900 and the NRD15.3 can range from 0-1500. To rescale it to a range of 0-100 the NRD9.3 and NRD15.3 will be divided by 9 and 15 respectively. A score of 100 represents complete adherence to the nutrient recommendations included in the metric.

4.1.3 Performance metric 3: Energy balance

The food and nutrient based performance metric will capture the quality of the diet including the variety of foods and nutrients consumed. However, because they are standardized for energy, they do not capture the energy balance. A measure that reflects the balance between energy intake and energy expenditure, is the Body mass index (BMI). The percentage of a population having 'normal' weight will be used as a third performance metric. Were 100% having normal weight is 'ideal'.

Individual variables

In the national surveys that we use in SUSFANS, we collected additional information on several population characteristics, including height and weight. We are thus able to calculated individuals' BMI and calculated population averages. We have to note that these data are self-reported and not based on anthropometric measurements. Usually people tend to underestimate their weight when it is self-reported. However, these difference are expected to be relatively small. In the Czech Republic differences between self-reported and measured normal weight ranged from 7.7-9.6% (Čapková, 2016).

Performance metric

BMI is calculated by dividing an individual's weight (in kilograms) by his or her height (in meters squared), and is the most common method to quantify weight across a range of body sizes in adults. Using BMI, individuals can be classified as normal weight (18.5–24.9 kg/m2), overweight (25–29.9 kg/m2), and obese (>30 kg/m2) (WHO, 1995). It reflects both health and nutritional status and predicts performance, health, and survival (WHO, 1995). BMI is often used as a proxy for body fatness in large population studies. Correlations between BMI and more direct measures of body fatness are generally strong (r>0.70) (Flegal, 2009; Ranasinghe, 2013; Ablove, 2015; Bradbury 2017).

4.1.4 Extrapolation to EU

We have data available for 4 countries (Czech Republic, Denmark, France and Italy). These countries represent the different regions in Europe (North, east, South and West) and account for ~30% of the European population. To estimate the performance metrics on the EU level we suggest to take the average of those for countries as they are equally spread across the EU and represent the North, South, West and East of Europe. When data will become available for other EU countries (EFSA comprehensive database) we can include those.

Table 4. Performance metrics for Policy Goal: 'Balanced and sufficient diet for EU citizens'

Policy Goal	**Performance metrics** (assessable against targets; B derived from C)	**Aggregate indicators** (C, derived from D)	**Derived variable** (D, derived from E)	*Cut-off for D*	**Individual variable** (E)
Balanced and sufficient diet for EU citizens	Food based summary score based on 5 key foods (0-100): • Fruits • Vegetables • Fish • Red & Processed meat intake • Sugar Sweetened Beverages (SSB)	n.a.	• Vegetables • Legumes • (Unsalted) nuts and seeds • Fruits • Fish • Dairy • Red/ processed meat • Hard cheese • Sugar sweetened beverages • Alcohol • Salt	≥200 g/d ≥150 g/week ≥15 g/d ≥200 g/d ≥150 g/week ≥300 g/d ≤500 g/week ≤150 g/week ≤500 mL/week ≤10 g/d ≤6 g/d	*Intake of >1500 food products have been individually assessed in country specific population surveys and have been aligned with FoodEx2 classification system*
	Nutrient based summary score (0-100) • NRD 9.3 • NRD 15.3	n.a.	**NRD 9.3** includes protein, dietary fibre, calcium, iron, potassium, magnesium, and vitamin A, C and E, saturated fat, added sugar, and sodium. **NRD 15.3** additionally includes mono-unsaturated fatty acids, zinc, vitamin D and B-vitamins (B1, B2, B12, folate), but excludes magnesium.	*See protocol D2.2*	Energy Protein Mono-unsaturated fat Fibre Calcium Iron Magnesium Potassium Selenium Iodine Zinc Vitamin A Vitamin C Vitamin E Vitamin B1 Vitamin B2 Vitamin B6 Vitamin B12 Folate Vitamin D Sodium Saturated fat Total sugar Protein, plant Protein, animal Saturated Fatty Acids (SFA) Mono-Unsaturated Fatty Acids (MUFA) Poly-Unsaturated Fatty Acids (PUFA)
	Energy balance % of population with normal weight: 100% is 'ideal'		BMI (kg/m2): normal weight: 18.5–24.9 overweight: 25–29.9 obese: >30 kg/m2		BMI (body mass index of each country)

4.2 Policy Goal: Reduced environmental impacts of the EU food system

Our society is facing multiple threats to our environment deteriorating the quality of the air, the water, the soil, changing our climate, or reducing the genetic resources or material resources (EEA 2015). The 7th Environment Action Programme (EAP) of the European Union sets out the vision that "in 2050, we live well, within the plant's ecological limits" setting three key objectives[4]: (i) protect, conserve, and enhance the Union's natural capital, (ii) turn the Union into a resource-efficient, green and competitive low-carbon economy, and (iii) to safeguard the Union's citizens from environment-related pressures and risk to health and wellbeing (EU 2013a). Global climate change is one of the largest environmental challenges humanity is facing and considerable efforts are required to limit global warming well below 2.0 or even at 1.5 degree Celsius as indicated in the Paris Agreement in 2016 (Rogelj *et al.* 2016). According to Steffen et al. (2015b), biogeochemical flows of nitrogen (N) and phosphorus (P), as well as genetic diversity are in the 'zone' of high risk, exceeding the planetary boundaries at global and regional level.

For the SUSFANS project we therefore define four performance metrics with the aim to achieve:

- Climate stabilization
- Clean air, soil and water
- Biodiversity conservation
- Preservation of natural resources

A recent assessment of the impact of agriculture on five main threats (climate, air, soil and water quality, and biodiversity) concluded that agriculture is a significant contributor for most of the environmental threats assessed is dominating some of them, e.g. contributing 55% of air pollutant emissions, 59% of the N burden of the water systems, and being responsible 51% of loss of biodiversity in Europe (Leip *et al.* 2015b). Seafood production causes considerable pressures on marine ecosystems, of various degree and form in different areas and from different production systems (e.g. Emeis *et al.* 2015; Halpern *et al.* 2015).

[4] See also http://ec.europa.eu/environment/action-programme/

Table 5. Emissions of main pollutants in Europe and share of agricultural sources. Values are calculated on the basis of the life-cycle (cradle-to-farm gate) approach; emissions from imported feed are not considered for comparability with estimates for EU27 ter

	Total Agricultural LCA flow within EU27 territory	Total EU27 budget flow	Share agriculture
Air pollution - NH3 emissions [Tg N yr-1]	2.6	2.7	94%
Air pollution - NOx emissions [Tg N yr-1]	0.3	2.6	13%
Air pollution - SO2 [Teq yr-1]	0.021	0.35	6%
Air pollution - NOx + NH3 emissions [Tg N yr-1]	2.9	5.3	55%
Soil acidification [Tg Teq yr-1]	0.18	0.56	32%
GHG emissions [Tg CO2eq yr-1]	651	4889	13%
GHG emissions - Carbon sequestration [Tg CO2eq yr-1]	-93	-170.5	55%
GHG emissions - GHG + Carbon sequestration [Tg CO2eq yr-1]	558	4718.4	12%
Water pollution - N [Tg N yr-1]	5.4	9.1	59%
Water pollution - DIP [Tg P yr-1]	0.025	0.25	10%
Land Use [Mio km2]	1.8	4.2	42%
Loss of biodiversity [relative MSA]	-34%	-65%	51%

In the following, we describe the SUSFANS approach to quantify each of the performance metrics on the basis of suggested aggregate indicators and their importance for the performance metrics (weighting factor) as well as a possible vision for the indicators that can be used to benchmark progress towards reaching the desired goals.

All environmental aggregate indicators should consider the impact from a life cycle perspective of a supply chains for a food product. This comprises emissions from agricultural activities (both the cropping and animal sector for livestock products), but also emissions from agricultural inputs (related to energy and land use, fertilizers, chemical substances etc.) and emissions from post-farm gate processes (processing, transport, consumption).

An overview of all metrics for the environment goal can be found in Table 6.

4.2.1 Performance metric 1: Climate stabilization

The societal goal of climate stabilization can be quantified with a single aggregate indicator measuring the “reduction of total GHG emission caused by the agri-food chain”.

4.2.1.1 Reduction of total GHG emission caused by the agri-food chain

Description: Total GHG emissions are measured as the global warming potential of climate relevant gases in CO_2-equivalents for a time horizon of 100 years caused by agricultural supply chains. Carbon equivalent emissions are calculated based on the global warming potentials as defined in the IPCC Fourth Assessment Report (Ipcc 2007): $GWP_{CH4} = 25$; $GWP_{N2O} = 298$. Even though more recent global warming potentials are available from the Fifth Assessment Report (IPCC 2014) ($GWP_{CH4} = 28$; $GWP_{N2O} = 265$), those are not yet used in official national greenhouse gas inventories and results were not comparable with policy targets or reported emission trends.

Policy vision: A stabilization of the climate at a level well below 2 degree Celsius above could imply that the current level of greenhouse gases would need to be reduced thus CO_2 re-captured from the atmosphere (Hansen *et al.* 2008). Possible sinks for CO_2 is the land use sector (already today acting as a net sink in Europe, (EEA 2014)), the agriculture sector (Lal 2016), or technical carbon capture and storage, potentially related to bioenergy production. Emissions of CH_4 and N_2O are natural biogeochemical processes it will be impossible to completely eliminate those emissions. As it is currently not predictable how much carbon sequestration in the agriculture sector will be required *beyond the amount required to compensate* own GHG emissions, we define thus as policy vision: zero net emissions from food products supply chains by the year 2100.

Policy targets: Policy targets for the whole EU economy are set in the 2020 climate & energy package (European Union 2015), the 2030 climate and energy framework (European Commission 2014), and the roadmap for moving to a low carbon economy in 2050 (European Commission 2011a). These documents however do not give specific targets for the agriculture sector. However, larger emission cuts are foreseen for the sectors covered by the EU Emissions Trading System which should reduce emissions by -43% by 2030, while the so-called ‘non-ETS sectors’ (including road transport, buildings, waste, agriculture and LULUCF) would need to reduce emissions by -30%, according a proposal[5] for

[5] https://ec.europa.eu/clima/policies/ets/revision_en

the revision of the ETS and for an Effort Sharing Regulation for emissions in non-ETS sectors[6].

Aggregated variables: The radiative balance of the atmosphere is affected from both the presence of greenhouse gases in the atmosphere, but also from reflections of solar radiation on surfaces. Ideally, a comprehensive analysis would cover two 'derived variables' quantifying total CO_2-equivalents emissions caused the supply chain or the agri-food system assessed, and the changes to the energy balance via land use/cover changes or contributions to changes in the water balance (Alkama & Cescatti 2016). Greenhouse gases include the main gases CO_2, CH_4, and N_2O that are emitted from agricultural and energy sources, but also emissions of climate-forcing cooling agents or other substances that might be released in the production chain, which can give a substantial contribution to GHGs of seafood from capture fisheries (Ziegler *et al.* 2013). In SUSFANS, only the emissions of greenhouse gases will be considered.

4.2.2 Performance metric 2: Clean air and water

Clean air and water resources are essential for the functioning of ecosystems, enabling them to provide the services for the benefit of society, and avoiding health impacts. The benefits derived from ecosystem services cover various dimensions of human well-being, namely basic human needs, economic needs, environmental needs and subjective happiness (Maes *et al.* 2016).

Aggregate indicators considered include therefore the reduction of emissions to the atmosphere and to the hydrosphere, as well as the reduction of toxic substances. Main pollutants of relevance in agri-food supply chains are emission of N and P compounds. A main concern for the quality of drinking is the presence of nitrates, while a balance between N and P determines the risk of fresh- and coastal water bodies to eutrophication (Garnier *et al.* 2010; Leip *et al.* 2015b).

In SUSFANS, the following aggregate indicators are therefore considered:

- Reduction of N surplus
- Reduction of N emissions to the atmosphere (air pollution)
- Reduction of N emissions to the hydrosphere (water pollution)
- Reduction of P surplus
- Reduction of Toxic substances use

4.2.2.1 Reduction of N emissions to the atmosphere (air pollution)

Description: Emissions of ammonia (NH_3) and nitrogen oxides (NO_x) are impacting air quality with direct health effect, for example through the

[6] https://ec.europa.eu/clima/policies/effort/proposal_en

formation of particulate ammonium nitrates, and contributing to multiple ecosystem damages through deposition. They are precursors of the greenhouse gas N_2O and thus also contributing to global warming. However, in areas with little nitrogen deposition, additional input of nitrogen through atmospheric deposition might also lead to an increase of biomass growth (fertilization effect) (De Vries *et al.* 2011). Also atmospheric nitrogen compounds might be, 'filtered' out with landscape elements protecting more sensitive (semi)natural ecosystems.

Policy vision: Policy vision is to eliminate emissions of harmful atmospheric pollutants. If possible the 'net' emissions shall be calculated, which means that recovered nitrogen emissions are subtracted from total emissions and emissions not contributing to any adverse effect are not accounted for. For the purpose of SUSFANS, we assume that in Europe nitrogen saturation of ecosystems is predominant thus all emissions are to be considered. Also, landscape structural elements for reducing nitrogen pollution are not yet in place and are assumed to be irrelevant. Therefore, the policy visions translate to zero NH_3 and NO_x emissions from agricultural supply chains. In analogy to the policy vision 'climate stabilization' we select the target year 2100.

Policy targets: The National Emission Ceilings Directive (NECD) (EC 2001) has the objective to limit emissions of acidifying and eutrophying pollutants and ozone precursors in order to improve the protection in the Community of the environment and human health against risks of adverse effects from acidification, soil eutrophication and ground-level ozone and to move towards the long-term objectives of not exceeding critical levels and loads and of effective protection of all people against recognised health risks from air pollution by establishing national emission ceilings.

The emission ceilings are defined at the national level, for the agriculture sector emissions of ammonia (NH_3) are most relevant, as more than 90% of NH_3 emissions originate from agricultural sources. The directive requires Member States to draw up a National Programme which includes information on adopted and envisaged policies and measures and quantified estimates of their effects on the emissions. Parallel to the development of the EU NEC Directive, the EU Member States together with Central and Eastern European countries, the United States and Canada have negotiated the "multi-pollutant" protocol under the Convention on Long-Range Transboundary Air Pollution (the so-called Gothenburg protocol, agreed in November 1999). The emission ceilings in the protocol are equal or less ambitious than those in the NEC Directive.

The NECD was being reviewed as part of The Clean Air Policy Package (European Commission 2013) and the new National Emissions Ceilings Directive entered into force in December 2016 (EU 2016) as the main legislative instrument to achieve the 2030 objectives of the Clean Air Programme. This Directive sets national reduction commitments for the five pollutants (sulphur dioxide, nitrogen oxides, volatile organic compounds, ammonia and fine particulate matter) responsible for acidification, eutrophication and ground-level ozone pollution which leads to significant negative impacts on human health and the environment.

Reduction commitments are given for 'any year from 2020 and 2029' and for 'any year from 2030' compared to the emission level in the year 2005. For EU28, the targets are -42% and -63% for NO_x, and -6% and -19% for NH3. However national targets vary considerably among countries, for the example of NH_3 emission reductions from 2030 onwards, they are between -1% for Estonia and -30% for Slovakia (EU 2016).

Aggregated variables: Emissions of NH_3 and NO_x are aggregated to the unit of total N emissions.

4.2.2.2 Reduction of N emissions to the hydrosphere (water pollution)

Description: Anthropogenic increase of nitrogen in water poses direct threats to human and aquatic ecosystems. High nitrate concentrations in drinking water pose a risk for human health (van Grinsven *et al.* 2010, 2006). In aquatic ecosystems the nitrogen enrichment can contribute to eutrophication events, which are responsible for toxic algal blooms, water anoxia, fish kills and habitat and biodiversity loss. (Grizzetti *et al.* 2011). Pressure of nitrogen loads in water comes from point sources (sewage systems), diffuse sources through leaching and runoff from agricultural production or diffuse input from (semi)natural ecosystems. For the year 2002, Leip et al. (2011a) estimate a share of agricultural sources to be 57%, sewage systems 22%; however the authors include also a large contribution from nitrogen input through atmospheric deposition on land or continental shelf regions. As sewage treatment considerably improved during the last decade, the share of agricultural nitrogen is likely to be higher today. Contribution to eutrophying emissions from aquaculture mainly comes from the grow-out site where the species is farmed, even if feed in aquaculture to a large extent originate from crop production.

Marine Strategy Framework Directive (EU 2008) aims to achieve Good Environmental Status (GES) of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend. The directive has a special descriptor for eutrophication with the goal "Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters".

Policy vision: Policy vision is to eliminate emissions of nitrogen emissions to the hydrosphere. If possible the 'net' emissions shall be calculated, which means that recovered nitrogen emissions are subtracted from total emissions and emissions not contributing to any adverse effect are not accounted for. Even though buffer zones and artificial wetlands are already used for the restoration of water courses, no suitable data is available allowing the quantification of the magnitude of their impact. Therefore, for the purpose of SUSFANS, we use zero nitrogen leaching and run-off as the policy vision. Again, in analogy to the policy vision 'climate stabilization' we select the target year 2100.

Policy targets: The Nitrates Directive (EC 1991) forms an integral part of the Water Framework Directive (EU 2000) and is one of the key instruments in the protection of waters against agricultural pressures. It has the objective reducing water pollution caused or induced by nitrates from agricultural sources and preventing further such pollution. The directive requires the Member State to monitor nitrate concentrations in surface water and groundwater, identify waters affected by pollution and waters that could be affected by pollution if no measures are taken and designate vulnerable zones where action programmes containing measures to reduce and prevent nitrate pollution must be developed, implemented and revised every four years. The corner stones of the directives are (i) the designation of vulnerable zones; (ii) the establishment of a Code of Good Agricultural Practice, and (iii) the implementation of Action Programmes describing required measures. Such Action Programmes can vary regionally depending on local conditions and pollution levels. The only pre-scribed quantitative measure given in Annex III of the ND is the limit of applied livestock manure of 170 kg ha^{-1} yr^{-1}. However, some countries have asked derogation. Currently there are eight derogations in force. As such, it is difficult to formulate a concrete policy target for the reduction of emissions of nitrogen to water. Furthermore,

- There is a strong regional variability in the effect of nitrogen emissions to water, also reflected in the designation of 'nitrate vulnerable zones'
- The nitrates directive focuses on the impact of nitrates on drinking water, while other effects linked other effects such as eutrophication of coastal zones are regulated in regional policies, such as the OSPAR convention, where 15 Governments and the EU cooperate to protect the marine environment of the North-East Atlantic.[7]

In 2015, the EU court of justice ruled in a case ("Weser case") that a country must refuse authorisation for projects that may cause deterioration of the status

[7] http://www.ospar.org/about

of a water body, unless derogation is granted. Deterioration of the status is given as soon as one quality element (Annex V of the directive) falls by at least one class.[8]

For SUSFANS, we therefore suggest use the linear interpolation of the emission level in the reference year and zero emissions by 2030 to the policy target year.

Aggregated variables: Emissions of nitrates and organic nitrogen to the water are aggregated to the unit of total N emissions.

4.2.2.3 Reduction of N surplus

Description: The Gross nitrogen balance (or nitrogen surplus) is regarded as key indicator in many agri-environmental frameworks aiming at monitoring the effectiveness of agricultural and environmental policies. The Gross nitrogen balance is calculated from total N in manure excreted by animals and/or imported to a farm and other inputs such as biological nitrogen fixation, atmospheric deposition and other applied fertilizers, and N in outputs (crop and livestock products) (Eurostat 2013; Leip *et al.* 2011b). The N surplus therefore includes all losses to the environment (atmosphere and hydrosphere) from livestock and crop production systems.

Despite this 'overlapping' with the aggregate indicators 'Reduction of N emissions to the atmosphere' and 'Reduction of N emissions to the hydrosphere', the aggregate indicator 'Reduction of N surplus' is still important because N surplus is a very common indicator; it includes losses of N_2, which are not included in the other aggregate indicators and are relevant for resource use efficiency (Pelletier & Leip 2013). Closing of the nitrogen cycle – that is reduction of the need for new nitrogen fixation is seen also as one big challenge for the global planetary boundaries (Rockström *et al.* 2009; Steffen *et al.* 2015a)

The monitoring of Nitrogen balances is required for each Member State's RDP 2007-2013 as part of the EU's Common Monitoring and Evaluation Framework (CMEF, EU 2013b). The monitoring of Nutrient balances is relevant also in other policy domains such as: the Water Framework Directive (EU 2000) requiring Member States to protect and restore the quality of their waters; and the Nitrates Directive (EC 1991), aiming to reduce water pollution caused or induced by nitrates from agricultural sources and prevent further such pollution.

In contrast to the other aggregate indicators, the N surplus is calculated per area of utilized agricultural land required for the production of a food product (including land for feed) and represents thus not the total absolute emissions in

[8] http://curia.europa.eu/juris/document/document.jsf?text=&docid=165446&pageIndex=0&doclang=EN&mode=req&dir=&occ=first&part=1&cid=9592

kg N yr^{-1} cause by the food chain, but the average losses of nitrogen to the environment per hectare of land used [kg N ha^{-1} yr^{-1}].

Policy vision: Due to the overlapping of the N surplus with emissions of nitrogen to atmosphere and water, no separate policy goal vision to be formulated. The N surplus has no influence on the performance metrics ‘clean air and water’ (weight=0) as it is already covered by the mentioned aggregate indictors.

Policy targets: not applicable.

Aggregated variables: Balance of total N inputs and total N outputs: Inputs: mineral fertilizer, manure imported to the farm or excreted by animals, other organic fertilizers applied, atmospheric deposition, biological nitrogen fixation. Outputs: N in crop products harvested and livestock biomass and livestock products sold.

4.2.2.4 Reduction of P surplus

Description: Phosphorus and phosphates contribute to aquatic (freshwater and marine) eutrophication and to coastal water eutrophication by providing limiting nutrients to algae and aquatic vegetation in excess of natural rates, leading to an alteration of aquatic species composition and productivity (Henderson 2015). Leip et al. (2015b, see Supplementary Information S4) assessed the limiting factor for a total of 24 European watersheds with the GREEN model (Grizzetti *et al.* 2012) on the basis of the ICEP approach (Garnier *et al.* 2010) and found most watersheds being P rather than N limited. Emissions of P to the atmosphere are usually considered negligible and occur mainly via wind erosion processes. Therefore, the P surplus aggregated indicator can be used for describing P losses to the aquatic system. P is less mobile in soils than N and might be ‘sorbed’ to soil minerals and thus become unavailable to plant uptake, but also not being at risk of contributing to water eutrophication (Redding *et al.* 2016). However, in contrast to N, P is a scarce resource, which needs to be ‘refilled’ from natural deposits if it is dispersed in to the environment. In SUSFANS, this ‘resource’ dimension is integrated into the aggregate indicator ‘reduction of P surplus’ which is therefore measured as the input of ‘new’ P to the food supply chain as mineral fertilizer, while recycled sources of P (in manure, compost, sewage sludge etc.) are not included.

Policy vision: Policy vision is a full recovery of P into the agro food system with zero P surplus and thus zero addition of new P. We select the target year 2100 in analogy to the climate stabilization aggregate indicator.

Policy targets: In the absence of quantified policy target for mineral P fertilizers, we use the linear interpolation of the emission level in the reference year and zero emissions by 2100 to the policy target year.

Aggregated variables: P application in mineral fertilizers.

4.2.2.5 Reduction of Toxic substances use

Description: Toxic substances, heavy metals and pesticides and other plant protection chemical substances and substances given to livestock pose a threat to organisms in the environment. Some substances are regulated, other are permitted to be use because sufficient evidence for the adverse effect has not been found, or because the benefit of the substances is believed to outweigh their risk. In SUSFANS we focus on pesticides and plant protection chemicals for which data are available in the models.

Policy vision: We set the policy vision is zero application of harmful substances by 2030. Ideally this takes into consideration the different levels of toxicity of different chemical agents if this information is available.

Policy targets: In the absence of quantified policy targets for the application of toxic substances, we use the linear interpolation of the emission level in the reference year and zero emissions by 2030 to the policy target year.

Aggregated variables: The aggregate indicator is derived from the individual variable on the usage of substances in the scope of plant protection and crop growth regulatory measures. In SUSFANS, no differentiation is made between different chemical products, as information on efficiency and harmfulness of the different agents used is not available. Therefore, all application of herbicides, fungicides, insecticides, as well as growth regulatory measures are considered. Aggregation is done based on a monetary value obtained e.g. from the Economic Accounts of Agriculture provided by Eurostat. The data is the sum of expenditures for all non-mechanical plant protection measures and is corrected by the inflation rate to account for price changes between the reference and the target year.

4.2.3. Performance metric 3: Biodiversity conservation

Food supply chains might affect biodiversity both directly through reduction of farmland biodiversity and marine biological diversity, and indirectly through land use change, land fragmentation, and pollution processes; pressures are often larger outside of the EU than within, masked by international supply chains (Lenzen *et al.* 2012). In SUSFANS, we assess biodiversity conservation with three indicators focusing on general terrestrial (non-farmland) biodiversity, farmland biodiversity, and marine biodiversity.

4.2.3.1 Reduction of the contribution of the agrifood chain to loss of Mean Species Abundance (MSA)

Description: Terrestrial biodiversity is affected through land use and pollution effects. Land use effects include (historic) land use changes, land fragmentation with consequently truncation of migratory routes (Reid *et al.* 2010). Pollution effect can be direct through deposition of nutrients affecting soil acidity and (micro)organism composition (Dise *et al.* 2011; Stevens *et al.* 2010), or indirectly via climate change (Alkemade *et al.* 2009).

The Mean Species Abundance (MSA) represents an index of the naturalness of an ecosystem. This indicator has been linked to causes of loss of species abundance in the GLOBIO-model (Alkemade *et al.* 2009; Kram & Stehfest 2012; van Vuuren *et al.* 2015) and attributes 64% of MSA loss to land conversions, 30% to land fragmentation and 5% to pressures from atmospheric deposition and climate change (Leip *et al.* 2015b).

Land use is therefore the single most important indicator for terrestrial biodiversity. It is measured in total area required for the food supply chain. It should be calculated on the basis of an LCA thus considering also land use embedded in imported (feed) products, multiplied with the total consumption of products. This aggregate indicator, however, is of importance beyond the relevance for biodiversity: low land requirements for agricultural production alleviates the pressure on land and reduces land competition. For example, according to current scenarios for the targets of 2 or 1.5 degree, afforestation and biomass production is needed, and the necessary area could go to 800 Mha by 2100 or higher (Popp *et al.* 2017); agriculture will need to contribute to making this possible.

Policy vision: No further increase for land used for agricultural production. In contrast to most of the other aggregated indicators, this is an absolute policy vision which needs to consider the number of persons.

Policy targets: Same as policy goal.

Aggregated variables: Land use [ha]

4.2.3.2 Agricultural land use diversity

Description: Agricultural land use diversity could be approximated by the concept of 'Biodiversity-Friendly Farming Practices' (BFP) which captures the causality between certain types of farming activity and their potential impacts on biodiversity. This is closely linked to the High Nature Value (HNV) farmland and is therefore a key indicator for the assessment of the impact of policy interventions with respect to the preservation and enhancement of biodiversity, habitats and ecosystems dependent on agriculture and of traditional rural landscapes. Terres et al. (2012) define BFP as a composite indicator with four sub-indicators (arable crops: Shannon index and N input index, grassland: stocking density index, permanent crops: N input, olive groves: surface).

The BFP indicator is calculated at high spatial resolution, such as the disaggregated results from the CAPRI model (Leip *et al.* 2015a).

In order to avoid duplication with other aggregate indicators, we use the Shannon index as proxy for agricultural land use 'patchiness' (Weissteiner *et al.* 2016) or diversity in SUSFANS. In contrast to most aggregate indicators, agricultural land use diversity cannot be calculated for individual food supply chains, as it intrinsically evaluates local crop diversity of agricultural systems. The aggregate indicator is therefore calculated as the average Shannon index of the farms/spatial units which contribute to the food supply chain.

Policy vision: A policy vision for agricultural diversity is difficult to define. The vision formulated in the states EU biodiversity strategy (European Commission 2011b) "By 2050, European Union biodiversity and the ecosystem services it provides — its natural capital — are protected, valued and appropriately restored for biodiversity's intrinsic value and for their essential contribution to human wellbeing and economic prosperity, and so that catastrophic changes caused by the loss of biodiversity are avoided.". We here tentatively set a goal of an increase of the Shannon index by two points until the year 2050. Note that this is a relative measure and interpretation might vary depending on the implementation of the Shannon index in different models. Possible, regional differentiated policy visions might be defined, taking protected areas and species hotspots into consideration.

Policy targets: Linear interpolation of the Shannon index calculated for the reference year and the value plus two points by 2050 to the policy target year.

Aggregated variables: The Shannon's entropy index H_r is a measure for the crop diversity in a region r, which is one of the 'greening' elements that had been introduced in the latest CAP reform (EU 2013c). The index is computed based on the agricultural sector's land use variety, i.e. the higher the number i of different crops p_i including grass cultivated and the more homogeneous their distribution (thus less dominance from few crops), the higher the diversity:

$$H_r = -\sum_{i=1}^{N} p_i ln p_i$$

H_r increases with the number of different land use types N and if their shares in the total agricultural area p_i are more equal. The index is zero if there is only one land use type p_i in the sector. In the CAP, crop diversity has to be evaluated at farm level, which is not possible with the models available in the SUSFANS toolbox. An evaluation at regional or country level is not meaningful, as the aggregation from farm to larger areas introduced an aggregation bias and disconnects the Shannon index from local crop diversity which is used as proxy for local biodiversity. In the CAPRI model, the Shannon index can be calculated on the basis of FADN single farm data using the CAPRI farm layer (see Leip *et al.* 2015a) or on the basis of homogeneous spatial units at the level of 1km x 1km pixels using the CAPRI spatial layer.

4.2.3.3 Marine biological diversity

Description: Seafood from capture fisheries represents the only large-scale food production based on a wild resource. It is sometimes argued that fisheries is be a good alternative to produce food with less impacts and resource use than many land-based protein production systems, as fisheries do not require inputs like feeds, fertilizers or pesticides. However, there are limits to natural production, and many stocks are overexploited and thus produce less than optimal. Direct and indirect ecosystem effects from over-exploitation include feedback such as altered ecosystem functioning (Howarth *et al.* 2014). This is manifested in the form of depletion of predatory fish (Christensen *et al.* 2003), collapse of major fish stocks (Pinsky *et al.* 2011), altered seafloor structure and function (Tillin *et al.* 2006) and biodiversity loss of target and non-target species (Dulvy *et al.* 2003; LEWISON *et al.* 2004). From an ecosystem production perspective, it has been estimated that current global fisheries exceed levels of sustainable exploitation, and have to decrease considerably to avoid risk of impaired function (Coll *et al.* 2008; Watson *et al.* 2015); the full effects of fisheries on marine ecosystems are still largely unknown.

Environmental pressures from aquaculture include: some species and farming practices require high level of feed input based on capture fisheries and may release invasive species, cause eutrophication, conversion of ecologically sensitive coastal land, and transmit diseases to wild fish (Diana 2009).

Policy vision: The vision of the descriptor on marine biodiversity in the Marine Strategy Framework Directive (EU 2008) states that the "quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions." There are also several other commitments, agreements and policies of relevance to the EU goals on marine biodiversity, to mention a few:

- The Convention on Biological Diversity (1992) is a multilateral treaty with commitments to conserve and sustainable use of biological diversity in order to halt rate of biodiversity loss. One proposed indicator is the Red List Index (RLI; Butchart *et al.* 2010, 2005), measuring the trend in proportion of threatened species occurring (species complexes or nationally).

- Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS), with the goal to protect marine mammals.
- The Birds Directive, protecting birds.
- The Habitats Directive, requires e.g. establishments of Special Areas of Conservation (target amounts) including marine habitats.

We set the SUSFANS policy vision to no adverse effects on marine habitats and non-commercial marine species from seafood production from either capture fisheries or aquaculture.

Policy targets: The descriptor for marine biodiversity in the Marine Strategy Framework Directive should be a good, overarching target for the SUSFANS policy vision. However, there are different national indicators to measure progress towards achieving Good Environmental Status of EU coastal waters by 2020, and many are not developed yet. Therefore, this cannot be included at this point.

Aggregated variables: Not applicable.

4.2.4 Performance metric 4: Preservation of Natural Resources

4.2.4.1 Sustainable water use

Description: Freshwater is regarded as one of the most important resources of the planet with agriculture being one of the largest consumers, with a current estimate of four billion people facing water scarcity today (Mekonnen & Hoekstra 2016). Climate change is likely to aggravate water scarcity and increase the number of people living with less than 500 m^3 of water per capita and year available (Schewe *et al.* 2014). Assessing sustainable use of water poses a particular challenge because of its large regional, but also temporal variability in water stress (Pfister & Bayer 2014) and the global water flows embedded in traded products (Vanham & Bidoglio 2014). The water footprint concept comprises the 'blue', 'green' and 'grey' water footprints, whereby the blue and green water footprints are associated with water consumption while the grey water footprint deals with water pollution (Hoekstra *et al.* 2011), whereby the green water footprints accounts for rain-fed water consumption and the blue water footprint for water evapotranspiration from additional irrigation water (Mekonnen & Hoekstra 2011).

Water use efficiency needs to increase substantially which is reflected in Sustainability Development Goals "Ensure availability and sustainable management of water and sanitation for all "[9], in particular target 6.4 (increase

[9] https://sustainabledevelopment.un.org/sdg6

water use efficiency) and here indicator 6.4.2 "Level of water stress: freshwater withdrawal as a proportion of available freshwater resources"

According to indicator 6.4.2, water stress is the ratio of water use (withdrawal) and water availability. Various authors point out that environmental flows that are required to maintain ecosystem services functioning need to be included (e.g. Mekonnen & Hoekstra 2016; Vanham *et al.* 2009). Also, return flows should be considered, thus using net rather than gross water abstraction (Mekonnen & Hoekstra 2016).

As many data required for a detailed assessment are not available for SUSFANS, we measures sustainable water as water consumption of blue and green water.

Policy vision: In theory, a zero blue water footprint is possible (Vanham & Bidoglio 2013); for the blue water footprint, we use a policy vision of zero blue water consumption in a food supply chain, recognizing however that zero blue water use is not realistic for some parts of Europe and also not required, depending on the renewal rate of blue water. However, also green water consumption might pose an environmental problem depending on the its impact on the local water stress and water environmental flows (Vanham & Bidoglio 2013). We therefore tentatively set a policy vision of a reduced green water footprint of 20% below reference situation. In accordance to the SDG target year, we set the target year for the policy goal to be 2030.

Policy targets: Linear interpolation to the policy target year as policy target, calculated from the water use calculated for the reference year and the value plus two points by 2030, or policy goal if the policy target year is 2030 or late.

Aggregated variables: Green and blue water consumption. If possible, they should be calculated separately, and their progress towards the policy goal averaged.

4.2.4.2. Sustainable exploitation of wild-caught seafood resources

Description: Capture fisheries have been proven to be challenging to manage. Research on how to define sustainable production levels has been intensive. One concept is the Maximum Sustainable Yield *MSY* (Mace 2001), the current management objective for yield in EU fisheries (EU 2014). Maximum Economic Yield *MEY* instead of *MSY* may allow for more profitable fisheries with a "biological buffer" (Marchal *et al.* 2016).

Today around 2500 species (or groups of species) are fished for, based on FAO landing statistics. Since the late 1980s, global production of capture fisheries has remained relatively constant; the limit has been reached. According to the latest estimates (2013), roughly 31% of the stocks were fished at unsustainable exploitation levels; 58% were fully fished whereas 11% under-utilized (FAO 2016)

Policy vision: The Common Fisheries Policy has set the target that stocks should be fished allowing for maximum Sustainable Yield (MSY) by 2020.

Policy targets: Distance to optimum exploitation F/F_{MSY} (see aggregated variables). Progress in this objective has been made in the northern fishing areas, while the Mediterranean shows little success (EU 2014).

Aggregated variables: Fishing pressure F and optimum fishing pressure F_{MSY} These values vary between stocks and years and are not yet available for all stocks exploited in the EU. They are reported on an annual basis by the International Council for the Exploration of the Seas (ICES) for stocks in the Northeast Atlantic.

4.2.4.3. Maintenance of soil fertility

Description: Soil quality is influenced by a large number of factors, including soil acidification, mainly through deposition of N compounds, level of organic matter (linked to the GHG balance), soil physical quality (e.g avoiding compaction and/or soil erosion). Several of these threats to soil quality are already covered in other aggregated indictors.

In SUSFANS we therefore assess the aggregate indicator 'maintenance of soil fertility' by defining soil degradation in terms of loss of soils by soil erosion.

Policy vision: Long term policy vision is an increase of soil organic matter in agricultural soils. At the climate change negotiations at the 21st Conference of the Parties to the United Nations (UN) Framework Convention on Climate Change (COP21) in Paris (November 30 to December 11, 2015), the "4 per Thousand" proposal was launched calling for a voluntary action plan to enhance soil organic carbon (SOC) content of world soils to a 40 cm (16 in) depth at the rate of 0.4% per year (Lal 2016; UNFCCC 2015).

Policy targets: In line with policy vision.

Aggregated variables: Loss of soil with soil erosion.

Table 6. Performance metrics for Policy Goal: 'Reduction of environmental impacts'

Policy goals	Performance metrics (assessable against targets; B derived from C)	Aggregate indicators (C, derived from D)	Derived variable (D, derived from E)	Individual variable (E)
Reduction of Environmental impacts	Climate stabilization	Reduction of total GHG emissions caused by the agri-food chain	CO_2 eq.	CO_2, CH_4, N_2O (Emissions according to IPCC categories incl. indirect land use change, per unit of product in food consumed (LCA) = C footprints)
				Use/emissions of cooling agents in fish production (CFCs)
			Radiative Forcing	Land Cover (e.g. albedo)
	Clean air and water	Reduction of N surplus	Nitrogen surplus	N input (fertiliser, manure, atmospheric deposition, biological fixation, feed) and N output (yield), change of soil stocks. Maybe split of N surplus into emissions to the atmosphere: air pollution and emissions to the hydrosphere: water pollution)
		Reduction of N emissions to the atmosphere (air pollution)	Emissions of Nr to the atmosphere (NH_3, NO_x)	Emissions of NH_3, NO_x
		Reduction of N emissions to the hydrosphere (water pollution)	Emissions of Nr to the hydrosphere (Nitrates, Organic N)	Emissions of NH_3, NO_x Emissions of NO_3, other run-off, leaching
		Reduction of P surplus	Phosphorus surplus	P input and output
		Reduction of Toxic substances use	Toxic substances use	Use of toxic substances (pesticides, …)
	Biodiversity conservation	Reduction of the contribution of the agri-food chain to loss of Mean Species Abundance (MSA)	Contribution to loss of Mean Species Abundance (MSA) calculated with the GLOBIO model (Alkemade et al., 2009)	Land use
				Emissions of GHGs, Nr
		Land use	Land use (Shannon)	The Shannon's entropy index (Hr)
				seafloor area impacted (m^2)
			Protected areas (GLOBIOM)	Land use map
			Species rich hotspots (GLOBIOM)	Land use map
		Reduction in number of threatened species	Red List Index (RLI)	IUCN Red List threat status (terrestrial and marine) of affected species
	Preservation of natural resources	Sustainable water use [e.g. maintenance of environmental flows]	Terrestrial water scarcity footprint	Irrigation water use
				Water use in livestock production
				Water use in the food chain
				Water supply
		Sustainable exploitation of wild-	distance to optimum exploitation	Fishing mortality (F)

	caught seafood resources	(F/FMSY)	
		%PPR relative to total available ecosystem production	primary production required (PPR)
	Maintenance of soil fertility	Soil degradation	Erosion
			Soil carbon contents

4.3 Policy goal: Competitiveness of EU agri-food businesses

This section aims at clarifying the comparative concept of competitiveness and at presenting the metrics to assess the competitiveness within the framework of the SUSFANS project. To that end, we:

1. Discuss the concept of competitiveness and present a definition of this concept that will be used in this study (Section 2).
2. Present an overview of competitiveness metrics. These metrics are derived from two perspectives: the competition on markets for the final product and the competition for inputs enabling production. The metrics are based on trade and production performances (Section 3).
3. Present the metrics from individual variables to the performance metrics for the spider diagram (Sections 3 and 4)
4. Discuss some issues, including the selection of countries and EU member states, the coverage in terms of sectors and industries, and the pertinent selection of deflators for the selected sectors and the overall economic activities for each country (Section 5).

We will not address the linkages between competitiveness and policies and we will not test the relation between competitiveness and performance on sustainable food security or economic issues.

All data can directly be derived from the GTAP model. These data are in monetary values and no quantities are available. All indicators will be based on the outcome of GTAP and always derived from values.

As for the terminology, we use the approach developed by the SUSFANS team:

E: Individual variable that is directly available from a database or a result of GTAP model.

D: Derived variable that is based on one or more individual variables. In the sections below, we add a number to these variables. For instance, D1 as first derived variable, D2 as second and so on.

C: Aggregate variable that evaluates a derived variable. This variable will be indicated with C and the number of the derived variable: e.g. C1 which will be linked to derived variable D1 and so on. However not all derived variables will be also an aggregate variable at C level. We will mention these few exceptions in the text and these are not included in the summary overview.

B: The performance indicator based on an aggregate variable.

A: Overall performance metrics that includes all performance indicators.

An overview of all metrics for the competitiveness goal can be found in Table 8.

4.3.1 Competitiveness: comparative and multidimensional

Competitiveness is often used in policy statements. The European Council expressed in 2000 the strategic goal that European Union has set for the next decade: *"...to become the most competitive and dynamic knowledge-based economy in the world..."* (European Council 2000). The Council assumes that a "competitive economy" contributes to a sustainable economic growth and more employment. However, in 1994 Krugman stated that from an empirical point of view the contribution of competitiveness to economic performance and policies is almost completely unfounded (Krugman 1994). The concept of competitiveness is complex as the following statement by Spence and Hazard (1998) illustrates it:

"The problem of international competitiveness has been defined in highly diverse ways. These definitions (and the proposed solutions to the problem) are partially inconsistent, and thoroughly confusing to most academics, politicians, policy-makers, and business managers. There is good reason for this confusion. The collection of problems alluded to, as "competitiveness" is genuinely complex. Disagreements frequently occur not only at the level of empirical effects and of policies, but also in the very definition of the problem." (Spence and Hazard 1998).

In this section, we will discuss elements of the concept competitiveness or aspects that are related to it. In next section, we will elucidate the indicators generally used for measuring competitiveness and the empirical background in order to minimize the confusion that might occur. Several authors (Buckley, Pass et al. 1988, Durand, Simon et al. 1992, Metcalfe, Georghiou et al. 1992, Krugman 1994, Crouch and Ritchie 1999, Latruffe 2010, Gorton, Hubbard et al. 2013, Siudek and Zawojska 2014) presented definitions of competitiveness and discussed the concepts and indicators.

Based on these papers, we can conclude that competitiveness is a comparative concept; it has different aggregation levels, is often multi-dimensional, it can be assessed by different theories, is defined in diverse ways for different time horizons. Furthermore, competition has two sides: selling your products or acquiring inputs. In other words, competition means on the one hand acquiring market shares for your final products and on the other hand to be able to buy means of production. Below these key words are discussed.

- **Comparative concept**: Latruffe (2010, p50) states that 'competitiveness should be measured with respect to a benchmark.' Competitiveness is a comparison between entities, e.g. firms or industries in different countries (Siggel 2006). The outcome depends on who is compared with whom and will accordingly differ with the selection of entities. Being successful in competition with one specific entity, does not mean that you are also successful in the competition with other entities. In this study, the outcome of the metrics fully depends on the selection of countries. In contrast to several other aspects of the SUSFANS approach, no fixed policy target can be defined for competitiveness. For that reason, a fixed selection of countries/or regions has to be defined and the performance metrics will be dependent on the outcome of the measurements of the selected countries. The level of the measure compared to benchmark countries indicates the level of competitiveness. Hence we compare the measures of country i with benchmark countries. The next example clarifies this point. The indicator is the world market share of country i, the competitiveness measure the growth of the export world market share of country i (difference of market share in period 2 compared to period 1). A growth of this measure as such is by definition not always strong. It will be indicated as strong if the benchmark countries have a lower growth or a decline. However, if the benchmark countries have a higher growth in market share than country i, the indicator will be valued as weak.

- **Aggregation level**: Competitiveness is measured for ‘goods or services, people, firms or countries’ ((Buckley, Pass et al. 1988), p177). In the economic literature also industries are often mentioned as competing entities (Latruffe 2010). E.g., the five competitive forces of Porter determine industry competition (Porter, 1990, p35). This study analyses the competitiveness of the EU food system or in our wording at industry level in a country/union. The food system can be disaggregated into several sub-industries. The GTAP/Magnet Model offers the opportunity to distinguish several subsectors e.g. food and drinks as total, dairy processing, meat processing or primary producers. Recognizing different groups of players along the value-chain enables analyses of the impact for these groups. Success of one industry can indeed go at the cost of an industry down- or up-streams within a country. For example, the successful industry might be able to negotiate low prices for the inputs which make the supplying industry less successful (Metcalfe, Georghiou et al. 1992).
- **Multi-dimensional**: Several authors stress that competitiveness cannot be defined by a singly indicator (Metcalfe, Georghiou et al. 1992, Sagheer, Yadav et al. 2009). Porter argues that in any industry five forces determine the long run competition, whether international or domestic, of an industry[10]. Each

[10] Namely: the threat of new entrants, the bargaining power of buyers, the bargaining power of suppliers, the threat of substitute products or services and the rivalry among existing firms.

force is built on several indicators (Porter 1980). Porter's diamond-shaped model for analysing competition between nation distinguishes four determinants, each of them also characterised by several sub-determinants for determining the competitiveness between nations (Porter 1990). Buckley et al. propose also several indicators, depending on the (aggregation) level of analysis and time horizon (Buckley, Pass et al. 1988). The World Economic Forum, for instance, distinguishes over 100 indicators divided in 12 pillars to access the global competitiveness of countries (Schwab 2014). Several indicators of the World Economic Forum can be indicated as institutional factors e.g. infrastructure or policies of the government. Siggel as well as Latruffe underline this need to include not only economic (costs, productivity, value added) and trade indicators (unit values, export indicators) but also institutional factors (Siggel 2006, Latruffe 2010). In our approach of the competitiveness, we will focus on economic and trade indicators. The other elements are addressed under different headings in other parts of the SUSFANS study. Furthermore, the dimensions for the analysis of competitiveness depend on the aim of the study. Krugman e.g. argues that it makes little sense to measure the competitiveness on the export market if the industry is (almost) fully focused on the domestic market (Krugman 1994). For that reason, we will include not only trade indicators but also indicators reflecting the domestic production performance and the importance of the domestic market.

- **Theoretical foundation**: Several theories or schools of thought aim at defining and analysing competitiveness (Siggel 2006, Latruffe 2010, Jambor and Babu 2016) resulting in a large number of definitions. From a strategic management perspective, competitiveness refers to the conduct of companies in shaping organisational advantages (Wright, Kroll et al. 1998, Thompson and Strickland 2003) and/or market advantages (Hamel and Prahalad 1994). Financial ratios (e.g. profit margin, current ratio, return on assets, debtor and collector period) are the metrics often used in accounting (Fleisher and Bensoussan 2003, Drury 2013). Measuring competitiveness with international economic indicators has its roots in Adam Smith's trade theory, which explains differences in competitiveness by way of absolute cost differences between countries. However, the application of new trade theories entails incorporating a wider array of aspects in the analysis such as product differentiation, innovation, economies of scale and productivity (Van Berkum and Van Meijl, 2000). O'Mahoney and Van Ark focus on productivity. In their study, productivity differences explain largely differences in competitiveness (O'Mahoney and van#Ark 2003). These are some examples of the impact of different theories on the metrics of measuring competitiveness. In this study, international economics will be used in deriving the metrics for competitiveness

- **Time horizon**: Several authors use sustainable gain in e.g. market share: hence a comparison between two periods and time horizons play a role (Siggel 2006). According to Porter (1980, 1990), sustainable competitive advantage is the fundamental source for above-average performance in the end. Buckley et al. (1992) introduce the dynamic aspect in the measurement of competitiveness based on three characteristics: competitive performance, potential and process, each with different indicators.
- **Inputs**: Being competitive means that the sector is able to source sufficient resources like labour, capital or raw materials. This means competition for inputs with other sectors. These two angles of focus – competition on markets for final products and on markets for inputs- are derived from the concept of comparative advantage. Comparative advantage has two dimensions:
  - Cost of uniqueness of the advantage. This requires a comparison between domestic and foreign sectors or products on a specific final market. Indicators related to the final product and the benchmark measure this concept.
  - Efficiency gap. Even if a sector performs well, other sectors might perform even better. For instance, the food sector of one country is the highest performer compared to the benchmark countries. However, on national level other sector might perform even better. In the long run, the sector that is thought to be successful performs less well than such partial competitiveness studies predict because other sectors in that specific country outperform this internationally high performing food sector (Van Berkum and Van Meijl, 2000). This is the competition for production factors: Is the performance of the sector compared to other sectors sufficient to compete successfully for means of production? Wijnands et al. make a comparison of the development of the value added with another sector (Wijnands and Verhoog 2016). Other measure could be labour productivity or total factor productivity (O'Mahoney and van Ark 2003).

Based on these considerations we use the following working definitions:

'**Competitiveness** is the ex-post performance of a sustained ability to achieve gains in value added, productivity, employment or world export market share'.

Competitiveness measures (in this study indicated as derived variables) are the difference of indicators between two periods. Competitiveness measures are indicated by with symbol "Δ" in the front of the indicator acronym.

Competitiveness performance is the comparative position of a selected country, selected sector in selected period. This performance measures is indicated by the symbol Δ*. The best performer is 100% the worst perform 0% for a specific sector, a specific (but fixed) selection of countries and/or member states and in specific period.

All variables are taken from GTAP in which products are aggregated into sectors[11]. To be consistent with the GTAP terminology we will not use the word products but sectors.

Box 1. Symbols, individual variables (E) and description

Indices	
b	Benchmark sector for comparing development of sector k=1,K. Proposed is to use the economy as a whole.
i	Reporting country, i=1, I
j	Partner or a) for exports destination respectively b) for imports origin country, if j=w it indicates the sum of all countries of the world, j=1,I
k	Sectors, k=1,K
t	Year
w	Indicates sum over all countries
Variables: all in USD, except food price index	
E_{ikt}	Employment of country i in sector k in year t. In contrast to most studies, in GTAP labour input is measured in value and not in quantity.
PI_{it}	Price inflation for country i in period t
GP_{ikt}	Gross Production by country i of sector k in year t
GVA_{ikt}	Gross Value added of country i for sector k in year t
m_{ijkt}	Import by country i of sector k from country j in year t
$m_{iwkt} = \sum_{j=1}^{I} m_{ijkt}$	Import by country i of sector k from all countries in the world (w) in year t
$mT_{iwt} = \sum_{k=1}^{K} m_{iwkt}$	Total export by country i of all sectors to world (w) in year t
$M_{kt} = \sum_{i=1}^{I} m_{iwkt}$	Total export of sector k by all countries in the world in year t
x_{ijkt}	Export by country i of sector to country j in year t
$x_{iwkt} = \sum_{j=1}^{I} x_{ijkt}$	Export by country i of sector k to world (w) in year t
$xT_{iwt} = \sum_{k=1}^{K} x_{iwkt}$	Total export by country i of all sectors to world (w) in year t
$X_{kt} = \sum_{i=1}^{I} x_{iwkt}$	Total world export of sector k by all countries in the world
$XT_{t} = \sum_{i=1}^{I} xT_{iwt}$	Total world export of all sectors by all countries in the world

[11] For detailed information: https://www.gtap.agecon.purdue.edu/databases/contribute/detailedsector.asp.

4.3.2 Performance metric 1: Production and trade - Openness and Self-sufficiency

Self-sufficiency and openness of a sector are related to production, imports and exports of a sector. Based on these three variables we can derive variables Openness (Open) and Self-sufficiency Ratio (SSR). The openness (trade dependency) indicator provides information on the dependency of the sector on imports and exports compared to the domestic production (Mikic and Gilbert 2009). This indicator has the advantage that is linked to the production of the economy and reflects the comments of Krugman that not only trade matters but also on the importance of the domestic consumption of domestically produced products (Krugman 1994). A growth of openness is evaluated as a positive development of the competitiveness as trade increases the competition between countries.

(D1)	$\mathrm{OPEN_{ikt}} = \frac{\mathrm{x_{iwkt}} + \mathrm{m_{iwkt}}}{\mathrm{GP_{ikt}}} * 100$	Openness of country i for sector k. Unit: %
(C1)	$\Delta\mathrm{OPEN_{ikt2}} = \mathrm{OPEN_{ikt2}} - \mathrm{OPEN_{ikt1}}$	Difference of the openness of country i between period t2 and t1 of sector k. Unit %

A second derived variable - the Self-Sufficiency Ratio (SSR) - is defined as: production times 100 divided by (production + imports - exports). SSR indicates the extent to which a country can rely on its own production. A ratio above 100 indicates a higher production than the domestic demand and below 100 a lower production than the demand (FAO 2016). A growth of the self-sufficiency is valued as a positive development of the competitiveness, as it measures the ability of a country to meet domestic consumers 'demand.

(D2)	$\mathrm{SSR_{ikt}} = \frac{\mathrm{GP_{ikt}}}{\mathrm{GP_{ikt}} - \mathrm{x_{iwkt}} + \mathrm{m_{iwkt}}} * 100$	Self–Sufficiency ratio of the country i for sector k. Unit: %
(C2)	$\Delta\mathrm{SSR_{ikt2}} = \mathrm{SSR_{ikt2}} - \mathrm{SSR_{ikt1}}$	Difference of the Self-sufficiency ratio of country i between period t2 and t1 of sector k. Unit %

4.3.3 Performance metric 2: Trade (export flow orientation, trade orientation and trade specialization)

4.3.3.1 Export flow orientation

Export growth is one of the most used indicators for competitiveness. Export market share depicts the importance of a country on the world market or on a specific market. The share as such is a poor indicator, as this depends amongst other on country's factor conditions. E.g. countries with a vast agricultural area can have a large production of commodities e.g. cereals production above the needs for their own domestic consumption. As competitiveness measure, we will take the difference between two periods of a country's export share on the world market. That market share is assessed separately for each period and hence despite a growing level of exports the share might decrease if total world exports grow faster. The growth is measured as the change in market share and not an annual growth rate between two periods. Annual growth rates between two periods have a strong flaw. Very small exporters can have large growth rates, but remain small exporters. Even with small growth rates, large exporters will have a large impact on the market. The definition of this indicator reflects the strong interdependency between exports of the different countries. By taking the absolute deviation, the real impact on the world market is taken into account as the total sum of all changes is by definition zero (Wijnands, Bremmers et al. 2008).

(D3)	$XS_{ikt} = x_{iwkt}/X_{kt}$	Export share of country i of sector k to the world (w) in year t. No unit
(C3)	$\Delta XS_{ikt2} = XS_{ikt2} - XS_{ikt1}$	Growth export share on the world market for sector k for country i between period t2 and t1. No unit

The industrial economics theory uses also a concentration index: the dependency on the most important export destinations. The Herfindahl-Hirshman Market concentration index is also suggested by the World Bank (WITS 2013). Another concentration index is the $C_{n:}$ the market share of the n-largest export destinations (Carlton and Perloff 1999). As our focus is based on the international economics thought, we will not include such a concentration indicator.

4.3.3.2 Trade orientation

The indicator above focuses on flows in one direction: exports. In this section, we take also imports into account. Some countries can record a high export performance based on transit activities e.g. due to an excellent logistic infrastructure or geographical position linked to demand regions.

The trade balance is one of the indicators for assessing the trade performance of the two-sided trade flows. The development of the trade balance shows whether the country is becoming more import or export dependent. The trade balance can vary between -∞ (net importing) and +∞ (net exporting) and is directly indicating the value of the net imports or net exports (Mikic and Gilbert 2009). The value is biased as it depends on the size of the economy. Large economies can have large net exports, however modest compared to the production. The development of this indicator as such is therefore poorly suited to measure competitiveness and mainly suited as descriptive measure.

(D4)	$\mathrm{TB_{ikt}} = \mathrm{x_{iwkt}} - \mathrm{m_{iwkt}}$	Trade balance of country i in period t is the sum of export minus all imports of sector k. Unit: USD

The second indicator, the Normalized Trade Balance (NTB), mitigates the level of exports and/or imports. The Normalized Trade Balance can be derived by dividing the trade balance by the sum of exports and imports. The advantages are that the indicator ranges between -1 (only import) and +1 (only export) and that an unbiased comparison between countries, products, and time can be made (Mikic and Gilbert 2009). However, the NTB is sensitive to the levels of imports and exports. Table 3.1 shows an example with equal trade balances, but different levels of trade. The NTB is higher if the levels of trade are lower compared to higher levels of trade.

Table 7. Example of sensitivity of the Normalized Trade Balance

Example	Export	Import	NTB	TB
1	70	20	0.56	50
2	150	100	0.20	50
3	230	180	0.12	50

As we are using the main exporting countries and the change in NTB for one specific country, we assume that the sensitivity to the trade level does not influence the results. The calculation of the NTB is as follows:

(D5)	$\mathrm{NTB_{ikt}} = \frac{\mathrm{x_{iwkt}} - \mathrm{m_{iwkt}}}{\mathrm{x_{iwkt}} + \mathrm{m_{iwkt}}}$	Normalized trade balance of country i in period t is the sum of export minus all imports of sector k. No unit.
(C5)	$\Delta\mathrm{NTB_{ikt2}} = \mathrm{NTB_{ikt2}} - \Delta\mathrm{NTB_{ikt1}}$	Difference of the normalized trade balance of country i between period t2 and t1 of sector k. No unit.

An increase in the indicator between 2 period means that exports grow faster than imports or imports decrease faster than exports. As competitiveness measure, we will use the difference between 2 periods: a grow signals to an improvement of competitiveness.

4.3.3.3 Trade specialization

In this section, Revealed Comparative Advantage indicators are presented: trade of one sector related to total trade. The importance of a sector in total trade is frequently measured by the Revealed Comparative Advantage (RCA) or Balassa index (Balassa 1965), also indicated as specialisation indicator. Comparative advantage is often an explanation for trade between countries. The RCA indicator can be calculated for imports and exports. The Revealed Comparative Export Advantage indicator (RXA) measures the export share of a product of one country in total export of that country relative to the world's export shares.

A RXA indicator of 1 indicates that exports of a product of the country is equally specialized as the total world exports. A level below 1 means relatively unspecialized and above 1 relatively specialized. The latter indicates an export advantage, as relatively more of that product is exported than the world average. In fact, it indicates the export focus of an industry and is therefore externally oriented.

A first flaw of this indicator is that re-exporting might suggest high competitiveness of one industry. These transit activities might be influenced by a good performance of another sector i.e. logistics or by beneficial natural and infrastructural conditions like sea or airports. This RXA indicator is often used in competitiveness studies as sole indicator (Frohberg and Hartmann 1997, Fertö and Hubbard 2003, Wijnands, Bremmers et al. 2008, Fischer 2010, Latruffe 2010, Carraresi and Banterle 2015, Jambor and Babu 2016). A second flaw is that the importance of the domestic market is neglected. A growing domestic demand signals a good competitive performance that might go at the costs of exports; the industry can grow with decreasing exports and even with decreasing imports.

Despite these flaws, it might be considered to include this measure in the analysis as it takes not only the exports of one product (such XS) but also the comparative position of one product in the whole export portfolio of a country. An alternative for RXA is the Additive Revealed Comparative Export Advantage (ARXA)[12]. The ARXA indicator is not as common as the RXA. The ARXA is the difference of the share of commodity in total exports of one country and the share of the world in total. As each share is between 0 and 1 the difference will be between -1 and +1 symmetric around zero. In fact, it measures the deviation of a country of world's total and by this indicating whether the country is less (ARXA below zero) or more specialised (ARXA above zero). This indicator can be interpreted more easily than the RXA. As competitiveness indicator, either the RXA or the ARXA will be used: we prefer the more commonly used RXA.

(D6)	$RXA_{ikt} = \frac{x_{ikwt} / xT_{iwt}}{X_{kt} / XT_{wt}}$	Revealed Comparative Export Advantage (RXA) indicator for sector k, country i in period t. No unit.
(C6)	$\Delta RXA_{ikt2} = RXA_{ikt2} - RXA_{ikt1}$	Growth RXA on the world market for sector k for country i between period t2 and t1. No unit

[12] The equation is as follows:

$ARXA_{ikt} = x_{ikwt} / xT_{iwt} - X_{kt} / XT_{wt}$	Additive Revealed Comparative Export Advantage (ARXA) indicator for sector k, country i in period t.

The opposite of the revealed export advantage indicator is the revealed import advantage (RMA). The interpretation of the indicator is reversed from that of RXA. A value below unity (=1) shows that country imports relatively less than the world average and can be indicated as a competitive advantage; a value above unity indicates a relatively higher import level. High levels or re-export of imported products, due to comparative advantage of other sectors or country's location, might explain a high value. This indicator as such is not an indicator for assessing competitiveness and will only be used to calculate the Revealed Net Trade Advantage (RTA).

(D7)	$RMA_{ikt} = \frac{m_{ikwt} / mT_{iwt}}{M_{kt} / MT_{wt}}$	Revealed Comparative Import Advantage (RMA) indicator for sector k, country i in period t. No unit.

An indicator that combines the previous 2 indicators is the Revealed net Trade Advantage (RTA) indicator. This is defined by Scott and Vollrath as difference between the RXA and RMA (Scott and Vollrath 1992). It has an advantage above the indicators based on either exports or imports as it includes both flows (Frohberg and Hartmann 1997). A positive RTA indicates a competitive advantage: exports exceed imports. Negative values indicate competitive disadvantages (Scott and Vollrath 1992).

(D8)	$RTA_{ikt} = RXA_{ikt} - RMA_{ikt}$	Revealed Net Trade Advantage (RTA) indicator for sector k, country i in period t. No unit.
(C8)	$\Delta RTA_{ikt2} = RTA_{ikt2} - RTA_{ikt1}$	Growth RTA of sector k for country i between period t2 and t1. No unit.

The Revealed Net Trade Advantage (RTA) indicators differ from the Normalized Trade Balance and Openness indicators mentioned above in respect to product orientation and the size of the economy. The RTA indicators take only the revealed trade position of a specific sector compared with all sectors into account. The Normalized Trade Balance and Openness are focused only on the performance of a specific product of a country compared to size of the economy. Therefore, both indicators are of importance.

The Michelaye Comparative Trade indicator (MRTA)[13] is an alternative of the RTA indicator, as it compares export shares with import shares of a specific sector of a specific country (Mikic and Gilbert 2009). This indicator takes values

[13] The equation is:

$MRTA_{ikt} = x_{ikwt} / xT_{iwt} - m_{ikwt} / mT_{iwt}$	Michelaye Comparative Trade indicator (MRTA for sector k, country i in period t.

between -1 and +1. If the value is negative, the country has a negative revealed (export) comparative advantage and if positive, it has positive advantage. The range between -1 and +1 enables a straightforward interpretation and is less complex to derive than the RTA. The nominators are the aggregated world total imports respectively the exports in theory these values should be on the same level except logistics costs: hence, the indicator indicates the net-trade as share in the total world trade. For consistency reason, we prefer the RTA indicator, as it is derived from the often-used Balassa index.

4.3.4 Performance metric 3: Production (Economic performance of a sector and productivity cross-sector benchmarking)

4.3.4.1 Economic performance of a sector

The European Council conclusion from 2000 set as strategic goals an economic growth and more jobs (European Council 2000). In economics, creating added value is an important indicator for economic growth and expresses industrial dynamism. Value added is seen as a better indicator than turnover as turnover includes also intermediate products, whereas value added is based on the production factors labour, capital and land. As inflation differences between countries will blur the real developments the nominal value added[14], this indicator has to be deflated. To derive the real value added at factor costs, the nominal value added is deflated by the Food Price index, also indicated as food inflation. However, this might be a preferred deflator for the food sector, it will be less suitable for deflating the Gross production of Value added of all economic activities of a country. For that reason, we choose the price inflation (PI) of all goods.

(D9)	$RVA_{ikt} = \dfrac{GVA_{ikt}}{PI_{it}}$	Real value added for sector k in in country i for period t. Unit: USD
(C9)	$\Delta RVA_{ikt2} = \dfrac{RVA_{ikt2} - RVA_{ikt1}}{RVA_{ikt1}}$	Growth RVA of sector k for country i between period t2 and t1. No unit.

This indicator as such, is not well suited as competitiveness measure. It is size sensitive: large countries or countries with a large industry will have a large value added. The derived variable is insensitive to size.

The derived variable above recognizes the economic growth. An obvious second competitiveness variable will be the growth of the jobs. However, in the GTAP model employment is not measured in persons but in monetary values. A

[14] The inflation measures the change in the costs that the average consumer has to pay for a basket for services and goods.

growth in this value can have two reasons: more persons employed or higher wages. For that reason, we have no competitiveness variable directly related to employment.

A comprehensive measure for competitiveness is Total Factor Productivity (Latruffe 2010): the ratio between an aggregation of all outputs and all inputs. However, this indicator might be biased by different qualities in inputs: e.g. ICT using sectors or capital-intensive sectors have higher levels of Total Factor Productivity (O'Mahoney and van#Ark 2003). Differences in levels between countries as well as changes might be incurred by the use of different technologies or by switching to more advanced technologies. Estimating the factors that determine the TFP is rather demanding. As the aim of this study is not to explain the levels or changes of TFP we will use the value added as productivity proxy. However, such a proxy is sector size dependent e.g. large countries will have a larger level of value added than small countries. For that reason, we will use the ratio of value added and total Gross Production. TFP is not sensitive for inflation as the nominator and denominator needed to be deflated by same Price index. The outcome is rather sensitive to the sign of the value of TFP in the first period. For instance, the growth is negative if the first year has a negative GVA and the second a positive value. We assume that in the GTAP-model the GVA is always positive.

(D10)	$TFP_{ikt} = \frac{GVA_{ikt}}{GP_{ikt}}$	Total factor productivity for sector k in in country i for period t
(C10)	$\Delta TFP_{ikt2} = \frac{TFP_{ikt2} - TFP_{ikt1}}{TFP_{ikt1}}$	Relative growth total factor productivity for sector k in in country i for period t

Real Labour Productivity (RLP) is often seen as a crucial determinant of competitiveness. Buckley et al (1988) classify productivity as an indicator for competitiveness potential. Labour productivity affects prices in the market. Due to due to different levels of Purchasing Power Parities (PPP) the absolute level of the RLP is a poor indicator and only comparable between countries after it has be adjusted to the Purchasing Power Parity (PPP). O'Mahoney and Van Ark use the growth in labour productivity as performance indicator (O'Mahoney and van#Ark 2003). Krugman and Obstfeld's statement underpins this choice:

'...absolute productivity advantage over other countries in producing a good is neither a necessary nor a sufficient condition for having a comparative advantage in that good.' (Krugman and Obstfeld 2006).

The Real Labour Productivity is the real value added divided by the number of employees. However, in GTAP employment is measured in monetary values and not in persons. In contrast to the usually interpretation labour productivity -

Value Added per unit labour input- now the labour productivity is the Value Added per USD labour input. If the same deflator for employment will be used, the monetary values do not need to be deflated; otherwise, the monetary value of employment has to be deflated.

(D11)	$RLP_{ikt} = \frac{VA_{ikt}}{E_{ikt}}$	Real labour productivity for sector k in in country i for period t. Unit: USD VA per USD E
(C11)	$\Delta RLP_{ikt2} = \frac{RLP_{ikt2} - RLP_{ikt1}}{RLP_{ikt1}}$	Relative growth real labour productivity for sector k in in country i for period t. Unit: USD VA per USD E

As productivity influences the prices on the final markets it can be seen as a cost competitiveness indicator or price indicator. Several authors mention costs or prices (unit value) as a competitiveness indicator (Buckley, Pass et al. 1988, Durand, Simon et al. 1992, Marsh and Tokarick 1994). These data are often linked to trade and domestic prices. The number of products from the agribusiness or food sector is numerous and hence a unit value comparison for one sector is almost impossible. A second disadvantage is that prices are focussed on the competition on one specific market, benchmarking exporting countries with the domestic production. In this case, cross-country comparison is focussed on just one market. In our approach, we benchmark countries at the world market. Due to difficulties to acquire adequate data and because of the focus, we compare only productivity indicators instead of actual prices.

4.3.4.2 Productivity – cross sector benchmarking

Above we discussed the competitiveness on the final markets (either foreign or domestic), in this section we focus on the competitiveness for means of production. The comparative advantage of the three above mentioned productivity indicators are considered to assess the competition for means of production. Buckley et all. (1988) mentioned the “% manufacturing in total output” as one of the performance indicators. This indicator covers the issue of comparative advantage of a sector. In addition, we prefer the added value above output or gross, following the approach of Wijnands et al. (Wijnands, Bremmers et al. 2008, Wijnands and Verhoog 2016). Value added indicates the rents on the production factors, whereas output (or turnover) might be the result of large level of inputs or intermediary products. As competitiveness indicator, we use not the absolute level but as for others the growth in the share similar to the other measures. The derived variables (measures) are straightforward.

For Value added:

(D12)	$$RRVA_{ikt} = \frac{RVA_{ikt}}{RVA_{ibt}}$$	Ratio real value added for sector k in benchmark sector b in country i for period t
(C12)	$$\Delta RRVA_{ikt2} = \frac{RRVA_{ikt2} - RRVA_{ikt1}}{RRVA_{ikt1}}$$	Relative growth ratio real value added for sector k in in country i for period t

For Total Factor productivity:

(D13)	$$RTFP_{ikt} = \frac{TFP_{ikt}}{TFP_{ibt}}$$	Ratio real total factor productivity for sector k in benchmark sector b in country i for period t
(C13)	$$\Delta RTFP_{ikt2} = \frac{RTFP_{ikt2} - RTFP_{ikt1}}{RTFP_{ikt1}}$$	Relative growth ratio total factor productivity for sector k in in country i for period t

And for Real labour productivity:

(D14)	$$RRLP_{ikt} = \frac{RLP_{ikt}}{RLP_{ibt}}$$	Ratio real labour productivity k in benchmark sector b in country i for period t
(C14)	$$\Delta RRLP_{ikt2} = \frac{RRLP_{ikt2} - RRLP_{ikt1}}{RRLP_{ikt1}}$$	Relative growth ratio real labour productivity for sector k in in country i for period t

4.3.5 The aggregation pathway from variables to metrics

The policy goal for competitiveness is a relative value: the most competitive or the best performing economy. For that reason, a value of an aggregate variable (above indicated by C#) has to be benchmarked to assess its comparative position. First, we present the data source. All individual variables (E-level) are available or will be available from runs with the GTAP model.

We distinguish at least 3 periods:

t1 Actual base year of GTAP

t2 Future year based on a run of GTAP. For this period several scenarios can be developed such as a baseline scenario (business as usual), full liberalisation of trade, or abolishment of free trade agreements and so on.

t0 Year in the past, it is recommended that t1-t0 is equal to t2-t1 for which similar GTAP data are available

A number of countries/regions are selected. These countries have to remain identical for each assessment, as these countries serve as benchmark countries for assessing the comparative position of each country on an aggregate variable (C-level). For possibilities to select countries or regions see:

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

A sector or a specific aggregation of sectors has to be chosen compliant with GTAP classification. See:

https://www.gtap.agecon.purdue.edu/databases/contribute/detailedsector.asp.

We suggest to include some levels of the value chain e.g. producers, food processors and retail. Furthermore, some large sectors e.g. the meat or dairy sector might even be recognized in the analysis. The metrics allow each level of sector detail, the selection of sectors depends on the overall aim of Susfans.

For each period, we have a set of aggregated variables for one sector covering all selected countries. Hence, the number of observations is equal to the number of selected countries. As competitiveness is a comparative concept, the "policy target" is being the best performing country or region. The "policy target" will therefore the maximum of the observations. This policy target differs for each period, each variable and scenario. If in t2 several scenarios are evaluated, the policy target will have to be determined for each scenario. With this information, the performance indicator at SUSFANS B-level can be derived. The performance metrics is the comparative position of a sector of a country in a period and is indicated by the symbols Δ* and are derived from the competitiveness measures with the symbol Δ. In Table 4.1 we suggest to take the average: a weighted average can be considered. The variables Δ* and the overall performance indicator A-level can be derived by following the SUSFANS metrics approac

Table 8. Performance metrics for Policy Goal: 'Competitiveness of EU agri-food business'

Policy goals	Performance metrics (assessable against targets; B derived from C)	Aggregate indicators (C, derived from D)	Derived variable (D, derived from E)	Individual variable (E)
Competitiveness of EU Food System	Production and trade	Difference of the **openness of country** i between period t2 and t1 of sector k. Unit % (C1)	**Openness of country** i for sector k. Unit: % (D1)	x_{ijkt}, m_{ijkt}, GP_{ikt},
		Difference of the **Self-sufficiency ratio** of country i between period t2 and t1 of sector k. Unit % (C2)	**Self–Sufficiency ratio** of the country i for sector k. Unit: % (D2)	
	Trade - Export flow orientation	**Growth export share on the world market** for sector k for country i between period t2 and t1. No unit (C3)	**Export share of country** i of sector k to the world (w) in year t. No unit (D3)	x_{ijkt}, x_{iwkt}, m_{iwkt}, ${}_xT_{iwt}$, X_{kt}, XT_{wt}, ${}_mT_{iwt}$, MT_{wt},
	Trade - Trade orientation		**Trade balance** of country i in period t is the sum of export minus all imports of sector k. Unit: USD (D4)	
		Difference of the normalized trade balance of country i between period t2 and t1 of sector k. No unit. (C5)	**Normalized trade balance** of country i in period t is the sum of export minus all imports of sector k. No unit. (D5)	
	Trade - Trade specialization	**Growth RXA on the world market** for sector k for country i between period t2 and t1. No unit (C6)	**Revealed Comparative Export Advantage** (RXA) indicator for sector k, country i in period t. No unit. (D6)	
			Revealed Comparative Import Advantage (RMA) indicator for sector k, country i in period t. No unit. (D7)	
		Growth RTA of sector k for country i between period t2 and t1. No unit. (C8)	**Revealed Net Trade Advantage** (RTA) indicator for sector k, country i in period t. No unit. (D8)	
	Production - Economic performance of a sector	**Growth RVA** of sector k for country i between period t2 and t1. No unit. (C9)	**Real value added** for sector k in in country i for period t. Unit: USD (D9)	GVA_{ikt}, PI_{it}, GP_{ikt}, V_{aikt}, E_{ikt}, GVA_{ibt}, GP_{ibt}, VA_{ibt}, E_{ibt}
		Relative growth total factor productivity for sector k in in country i for period t (C10)	**Total factor productivity** for sector k in in country i for period t (D10)	
		Relative growth real labour productivity for sector k in in country i for period t. Unit: USD VA per USD E (C11)	**Real labour productivity** for sector k in in country i for period t. Unit: USD VA per USD E (D11)	
	Production - Productivity cross-sector benchmarking	**Relative growth ratio real value added** for sector k in in country i for period t (C12)	Ratio **real value added** for sector k in benchmark sector b in country i for period t (D12)	
		Relative growth ratio total factor productivity for sector k in in country i for period t (C13)	Ratio real **total factor productivity** for sector k in benchmark sector b in country i for period t (D13)	
		Relative growth ratio real labour productivity for sector k in in country i for period t (C14)	Ratio **real labour productivity** k in benchmark sector b in country i for period t (D14)	

4.4 Policy goal: Equitable outcomes and conditions of the EU food system

Equity considerations are an intrinsic element of the food security discourse and have been propagated strongly by those who address food security as a basic human right. Since the seminal publications of Amartya Sen in the 1980s, it is commonly understood that food insecurity must be understood in a wide socioeconomic and cultural context, which deprives people from the opportunities to consume the food in the quantities and quality that they want and need.

Since the early 1990s, the number of people suffering from undernourishment decreased from about 1,011 million (19% of world population) to 795 million people (11% of world population) in 2014-2016 (FAO, 2015). On the one hand, this reduction reflects progress made in the fight against hunger; on the other hand, it shows that inequity among people who manage and people who do not manage to meet their food and health needs is still significant. This inequity is related to the daily living conditions of people: the social, economic and political conditions in which people are born, grow, live, work, and age (Friel and Baker, 2009). Hungry people are faced with daily living conditions that hamper them to grow sufficient food for themselves or to earn enough income to meet their food and health needs (Mulvany and Ensor, 2011).

Food and nutrition security (FNS) is a European problem as much as it is a global challenge, but with EU-specific features. The main challenge in the EU is the impact of poor diets on the disease burdens, i.e. the prevalence of both undernutrition and rising overweight and obesity. Both are to a large extent driven by socio-economic exclusion in the food system and other forms of inequity: the poor, ethnic minorities and the elderly are particularly vulnerable groups within the EU. Geographically, the FNS challenges are concentrated in the Eastern member states of the EU, where problems of poor food environments compound with compromised access to fresh and nutritious food products, in particular fruit and vegetables (Cockx, Francken and Pieters, 2015; Rizov, Cupak and Pokrivcak, 2015; Alexandri, Alexandri, Păuna and Luca , 2016). A growing number of people relies on food banks (Hebinck and Villarreal, 2016). In general, there is a need to analyse the quality of the food environment across the EU and its relation to the consumption choices, nutrition outcomes and health burdens from diet-related diseases.

The EU food system structure, policies of EU and member states related to food and agriculture and the various outcomes of the EU food system have a significant impact on how people around the world are able to meet their food requirements. This consideration led the SUSFANS team to formulate a fourth policy goal related to global FNS to capture how the EU impacts on global FNS. In consultation with the stakeholder core group of the project (SCG) this policy goal was broadened as stakeholders felt that the project should address a wider array of equity issues related to the EU food system as well. Stakeholders participating in the first two SCG workshops questioned how issues related to equity within in the food system, such as power relationships between food system actors, participation in decision-making or fair wages, and with respect to the food system outcomes, e.g. food poverty in the EU or global FNS, could be included in the analysis and therefore in the selection of metrics to assess SFNS. Earlier stakeholder consultations on policy visions and scenarios on global food and nutrition security presented similar interests (de Bakker et al., 2017). The SUSFANS team thus broadened the fourth policy goal and renamed it 'Equitable outcomes and conditions of the EU food system'. Different from the three other policy goals the Equity goal has not been formulated in detail within the context of metrics for FNS before and the project team is here breaking new ground in order to establish a set of meaningful metrics. For that the SUSFANS team is also consulting with experts outside of the project that work on equity considerations[15]. In addition, an internet survey and further probing with the stakeholder core group are planned to discuss the proposed metrics and indicators as these could not be discussed before in the two SCG workshops. Thus the list presented here is still indicative of the final list. In the consultations also the full set of metrics will be reviewed once more in order to establish if the full set of performance metrics for SFNS consists for the right mix and is formulated in a way that is easy to communicate.

Equity considerations are duly enshrined in the European treaties. A priori, however, there is no level or state of equity in society that will maximize social welfare. Equity itself is not known to have been the objective of a particular public policy. Public policies and programs are known to focus on addressing income inequalities, social exclusion and discrimination and lack of power or voice. These efforts contribute to greater equity in society rather than that they aim to deliver on a particular vision on what equity is desirable. That is a significant conceptual challenge for the design of performance metrics on equity in the food system. The policy targets against which to assess indicators on equity in the conditions and outcomes of food systems are missing.

[15] The SUSFANS team held a small workshop with experts from the Centre of Agroecology, Water and Resilience of the Coventry University, UK, where various team members work on issues such as food sovereignty, gender issues in food systems etc. This workshop helped to develop a first list of possible variables and indicators to consider and the SUSFANS team would like to gratefully acknowledge their contributions.

For a proper analysis of equity in SFNS it is proposed to include equities in daily living conditions of social groups, equities in the extent to which social groups are able to meet their food needs, and health equities among social groups. By doing so both causes (i.e. inequities in daily living conditions), direct results (i.e. inequities in meeting food needs) and indirect results (health inequities) can be taken into account. In this section some suggestions for the design of equity metrics for FNS are given. This design is built upon the various elements of the SUSFANS SFNS conceptual framework and covers equities in daily living conditions, meeting food needs and health. The metrics only reflect quantitative and qualitative inequities among social groups in relative terms without giving any value judgment.

Equity can be measured among actors within a country or between actors in different countries. Which option is applied depends on the purpose of the analysis. As SUSFANS is focussed on FNS in the EU in relation to global impacts, SUSFANS equity indicators are collected at country level in order to compare equity of actors in different countries, both between EU countries and between EU and non-EU countries.

Equity indicators can be expressed in absolute and relative terms. Most indicators on meeting food needs will be given in absolute terms, from which it is easy to assess the distance from the level of fully satisfying the need. On the other hand, most indicators on daily living conditions and health are given in relative terms, often as share of the population. It has to be noted that such shares can be expressed in both positive terms and negative terms, i.e. the share of population having more than 1$ a day and the share of population having less than 1$ a day. As we aim to construct aggregate indicators we have to take care that these are based on individual equity variables that are expressed in the same way: either negative or positive. In SUSFANS we express equity variables in negative terms. This implies that low shares are associated with more equity than higher shares.

In Table 10 a hierarchy of indicators for the equity policy goal is presented. The solution to overcome the challenge of addressing policy targets is pragmatically addressed case by case.

4.4.1 Performance metric 1: Equity among food chain actors and primary producers

The SUSFANS conceptual framework (D1.1) distinguishes between the conditions and structure of the food system and the outcomes of the system. This distinction is an important one for guiding the analysis of equity considerations for the food system. The conditions and structure are related to how the different actors in the system deal with each other and who holds the power within the system for deciding on the conditions in which food system actors, such as the primary producers and the food chain actors, carry out their activities. In order to capture the equity aspects in the conditions and structure of the food system, the SUSFANS team formulated a performance metric called 'Equity among food chain actors and primary producers', which aims to measure the extent of fair conditions in access to resources (land, capital, etc.) for producers and chain actors. The access to resources was seen as a tangible measure for understanding the structure of the EU food system and the distribution of power within the system. Three aggregate indicators were selected to measure these issues in more detail. The first one is the 'Access to resources for primary producers', which can be derived from variables such as the 'Share of farmers without legal ownership of farm land' and the 'Share of female farmers without access to agricultural land'. The second Aggregate Indicator is the 'Access to finance and technology', derived from variables such as the 'Share of farmers without access to microfinance', the 'Share of farm women without access to savings and credit' and the 'Share of farmers without primary education' and the 'Share of farmers without access to vocational training'. The third Aggregate Indicator is called 'Fair trading practices' which aims to capture power relationships in the EU food system by using the 'Share of farmers who are faced with a monopolistic downstream industry' and the 'Share of farmers who are faced with a monopolistic upstream industry' as the variables to describe this issue in more detail.

4.4.2 Performance metric 2: Equity among consumers: food system conditions

Also among consumers a number of conditions of the food system determine if different parts of the population have equitable access to food. Three Aggregate Indicators were selected that can describe the performance metric of 'Equity among consumers: food system conditions' and therefore show a picture of the conditions within which consumers are able to obtain food. The first Aggregate Indicator is called 'Wealth', which can be derived from the following variables 'National income per capita by region as percentage of the EU national income per capita', 'Household income per capita by region as % of EU household income per capita', 'Share of the population with less than 1$ a day', 'Share of the population that has no access to health care centres', 'Share of the population without access to sanitation facilities' and 'Share of the female population without primary education'. The second Aggregate Indicator used here is supposed to portray 'Political stability' as derived from the 'Share of the population living in political unstable conditions', the 'Share of the population without right to social security' and the 'Share of the population that has no access of safety nets such as food assistance or pensions'. The third Aggregate Indicator that can determine food access is called 'Consumer choices' and results from the two following variables, namely 'Share of the population without access to fresh food' and 'Share of the population whose food preferences are not met by food supply'.

4.4.3 Performance metric 3: Equity among consumers: food system outcomes

With respect to the outcomes of the food system the project considers here both the classical set of indicators for FNS as they are presented in the food security literature (availability, accessibility, utilization and stability) together with indicators measuring the health outcomes of the food system. For the FNS indicators the SUSFANS project bases its selection of variables on the work of the EU project FOODSECURE (www.foodsecure.eu) (Shutes et al. *forthcoming*). A summary of the available FNS Aggregate Indicators and their associated variables is provided in Table 9. Food and nutrition security indicators and the type of consumer and the scale in which they can be assessed

9. The variables have been developed based on the FAO suite of FNS indicators (FAO, 2016) as part of the FOODSECURE project.[16] A selection of the indicators have been used to evaluate food and nutrition security in four stakeholder developed visions of the future (see Shutes et al., 2017 for further details). The metrics presented in this section have been designed to match the data and model indicators in two assessment tools, i.e. the MAGNET model of Wageningen Economic Research and the GLOBIOM model of the International Institute for Applied Systems Analysis (IIASA).

Aggregate Indicator: Availability

Derived Variable: Calorie availability

This Derived Variable gives the total amount of net (kilo)calories available per capita per day for the average consumer globally, within the EU and non-EU regions and at the member states level. The indicator will also be available for different household types in the case study countries, giving insight into variations within these countries. The indicator is defined as the total calories imported and produced for domestic human consumption and therefore exclude calories in food exports and those in animal feed and biofuel feedstocks. The unit of this indicator is kilocalories per capita per day.

[16] The results of the FOODSECURE project, including an assessment of future scenarios for food and nutrition in the EU and globally, are available via the website www.foodsecure.eu/navigator.

Table 9. Food and nutrition security indicators and the type of consumer and the scale in which they can be assessed

FNS Dimension	Derived Variable	Type of consumer and scale: Average consumer worldwide, EU, non-EU and member state level	Type of consumer and scale: Household specific values in case study countries
Availability	Calorie availability	✓	✓
Availability	Share of nutritious food	✓	✓
Availability	Reduction in share of protein of animal origin	✓	✓
Availability	Domestic food production	✓	n/a
Accessibility	Share of food expenditure in total expenditures	✓	✓
Accessibility	National income per capita	✓	n/a
Accessibility	Food affordability	✓	n/a
Accessibility	Household income per capita	✓	✓
Accessibility	Consumption per capita	✓	✓
Utilisation	Share of calories from fruit and vegetables	✓	✓
Stability	Cereal import dependency ratio	✓	n/a
Stability	Value of food imports over total merchandise exports	✓	n/a
Stability	Market pressure index	EU	n/a

Source: EU project FOODSECURE, except for the market pressure index which is an original contribution of SUSFANS.

Derived Variable: Share of nutritious foods

The share of nutritious foods is defined as 1 minus the share of energy (kilocalories) derived from cereals (MAGNET[17]) or cereals, roots and tubers (GLOBIOM), where the calories from cereals or cereals, roots and tubers is the percentage share of total calories available for consumption. The unit for this indicator is percent.

Derived Variable: Reduction in share of protein of animal origin

This indicator focuses on the share of protein from animal origin (including or excluding fish) in total protein. The indicator is constructed so that an increase represents a reduction in protein from animal sources, reflecting the average over-consumption of protein in the European diet. Caution should be taken when interpreting this variable in relation to low-income countries where (animal) protein consumption may be below optimal levels.

[17] Roots and tubers are combined with fruit and vegetables in the MAGNET database.

Derived Variable: Domestic food production

The average value of primary food production is an indicator of the strength of the domestic food producing sector. It is defined over primary food rather than including food processing as it relates to the food availability dimension of food and nutrition security. The variable is defined per capita in constant (2010) prices.

Aggregate Indicator: Accessibility

Derived Variable: Share of non-food expenditure in total expenditures

The share of non-food expenditure in total expenditures is 1 minus the share of food spending in total spending for the average household. Higher shares of non-food expenditure in total expenditure are associated with higher food security as changes in food prices and incomes have less of a direct impact on food consumption i.e. they are insulated by having non-food income that can be diverted to food if necessary. This variable is also available by household type in the case study regions. The unit for this indicator is percent and excludes savings.

Derived Variable: National income per capita

National income per capita gives an indication of the wealth of a nation. It is measured as GDP per capita in constant US dollars.

Derived Variable: Food affordability

Food affordability is indicated by the real domestic primary food price index. The index can also be expanded to include processed food and weighted by consumption to reflect how price changes affect the average consumer and household types with different consumption baskets. In the latter case, the variable becomes household specific as common prices affect households different due to the different weights of food products in total food consumption.

Derived Variable: Household income per capita

Household income per capita is a further measure of wealth in a region which can be household specific due to different patterns of factor incomes in different household types. At the household level, the variable also accounts for different rates of population growth.

Derived Variable: Consumption per capita

Average and household specific food consumption per capita shows how changes in prices, incomes and population combine to affect food consumption.

The variable is a Paasche volume index of food consumption which includes primary and processed foods.

Aggregate Indicator: Utilisation

Derived Variable: Share of calories from fruit and vegetables

The standard FAO utilisation indicators centre on measures of physical development (e.g. stunting and wasting), health outcomes (e.g. anaemia) and water and sanitation. Given the limitation of economic models to inform these indicators, we introduce the share of calories from fruit and vegetables as a crude proxy for a healthy diet and micronutrient intake. The variable includes vegetables and fruits consumed directly, via processed products and via food services. The variable is expressed as a percentage of total calories consumed.

Aggregate Indicator: Stability

Derived Variable: Cereal import dependency ratio

This variable shows the degree to which a country or region is dependent on cereal imports. The variable is bounded at zero so all net exporters take this value. The variable is expressed as a percentage.

Derived Variable: Value of food imports over total merchandise exports

This variable provides a measure of vulnerability and captures the adequacy of foreign exchange reserves to pay for food imports, which has implications for national food security depending on production and trade patterns (FAO, 2016). FAO definition excludes fish which is included here. The variable is expressed as a percentage.

Derived Variable: Market pressure index

The volatility of agricultural markets has a profound impact on food and nutrition security (Kalkuhl, von Braun and Torero, 2017). For a given agricultural commodity, the market pressure index provides the percent difference between the actual price and the predicted price based on market fundamentals, macroeconomic and financial developments, as well as the dynamics of climatic variables (Crespo Cuarisma, Hlouskova and Obersteiner, 2017). The forecasting model used to obtain the predictions is chosen after an exhaustive scrutiny of the predictive ability of a large number of state-of-the-art multivariate time series specifications and combinations thereof. The index indicates whether the prevalent climatic and economic conditions are expected to lead to an increase or a decrease of the price of a particular agricultural commodity at a given horizon (from one to twelve months ahead) and by how much the price is expected to change.

Aggregate Indicator: Health - Undernutrition

In addition to the FNS indicators, this performance metric describing the equity among consumers with respect to food system outcomes also includes two Aggregate Indicators around health considerations. These were included because the project and many decision makers are concerned with understanding these specific outcomes in particular. One deals with Undernutrition and can be derived from the following variables ‚Share of population with a BMI smaller than 18.5‘, ‚Share of children under 5 with stunting‘, ‚Share of children under 5 with iron deficiencies‘, ‚Share of children under 5 with vitamin A deficiency‘, ‚Share of women at reproductive age with iron deficiencies‘, , Share of women at reproductive age with vitamin A deficiencies‘, , Share of population with insufficient dietary supply adequacy‘ and ‚Share of population with insufficient protein supply‘.

Aggregate Indicator: Health - Over nutrition

Not just undernutrition but also over nutrition, i.e. overweight and obesity, need to be considered. These can be expressed by the variables ‚Share of the population with BMI over 25 and ‚Share of the population with BMI over 30‘.

4.4.4 Performance metric 4: Equity in food footprint

A fourth performance metric for the equity goal wants to capture the notion that the EU food system’s environmental negative outcomes have an impact globally on natural resources, for example via GHG emissions from agriculture. Thus the team formulated a performance metric called ‘Equity in the food footprint’, which consists of two Aggregate Indicators. The first one is called ‘Resources embedded in and GHG emissions related to food consumption’ and is derived from the ‘Hectare of land per calorie consumed’, ‘Kilogram of fertilizer per calorie consumed’, ‘GHG emissions per calorie consumed’ and ‘Litre of water per calorie consumed’. The second Aggregate Indicator describes the ‘Resources embedded in and GHG emissions related to food production’. It results from the following variables: ‘Share of farmers applying environmentally friendly production methods’, ‘Share of farmers without education in the use of pesticide and fertilizer’, and ‘Share of farmers not applying GHG emission reduction techniques’.

Table 10. Performance metrics for Policy Goal: 'Equitable outcomes and conditions'

Policy goal	Performance metric	Aggregate indicator	Derived variable	International data source[1)]
Equity	Equity among consumers: food system outcomes	Availability	Calorie availability by region (EU, non-EU)	MAGNET
			Share of nutritious food by region (EU, non-EU)	MAGNET
			Reduction in share of protein of animal origin by region (EU, non-EU)	MAGNET
			Domestic food production per capita by region (EU, non-EU)	MAGNET
		Accessibility	Share of food expenditure in total expenditures by region (EU, non-EU)	MAGNET
			Food affordability by region (EU, non-EU)	MAGNET
			Consumption per capita by region (EU, non-EU)	MAGNET
		Utilization	Share of calories from fruit and vegetables by region (EU, non-EU)	MAGNET
		Stability	Cereal import dependency ratio by region (EU, non-EU)	MAGNET
			Value of food imports over total merchandise exports by region (EU, non-EU)	MAGNET
			Market pressure index	ApriPrice
		Health: Undernutrition	Share of population with BMI <18.5	
			Share of children < 5 years with stunting	WHO/UNICEF
			Share of children < 5 years with iron deficiency	WHO/UNICEF
			Share of children < 5 years with vitamin A deficiency	WHO/UNICEF
			Share of women at reproductive age with iron deficiency	WHO/UNICEF
			Share of women at reproductive age with vitamin A deficiency	WHO/UNICEF
			Share of population with insufficient dietary supply adequacy	FAO
			Share of population with insufficient protein supply	FAO
		Health: Overweight and obesity	Share of population with BMI >25	
			Share of population with BMI >30	
	Equity among consumers: food system conditions	Wealth	National income per capita by region as % of EU national income per capita	MAGNET
			Household income per capita by region as % of EU household income per capita	MAGNET
			Share of population with less than 1$ a day	World Bank
			Share of population that has no access to a health care center	World Bank
			Share of population without access to sanitation facilities	World Bank
			Share of female population without primary education	
		Political stability	Share of population living in a political unstable surrounding	
			Share of population without right to social security	FAO
			Share of population that has no access to a safety net (food assistance, pension)	

	Consumer choices	Share of population without access to a fresh food shop	
		Share of population whose food preferences are not met by food supply	
Equity among producers and chain actors	Access to resources by primary producers	Share of farmers without legal status of ownership of the farm land	
		Share of farm women without access to agricultural land	
	Access to finance and technology	Share of farmers without access to microfinance	World Bank
		Share of farm women without access to saving and credit	World Bank
		Share of farmers without primary education	
		Share of farmers without access to vocational training	
	Fair trading practices	Share of farmers who are faced with a monopolist downstream industry	
		Share of farmers who are faced with a monopolist upstream industry	
Equity food footprint	Resources embedded in and emissions related to food consumption	Ha of land per calorie consumed	MAGNET
		Kg of fertilizer per calorie consumed	MAGNET
		Litre of water per calorie consumed	
		Unit of emissions per calorie consumed	
	Resources embedded in and emissions related to food production	Share of farmers applying environmentally friendly production methods	
		Share of farmers without education in the use of pesticides and fertilizers	
		Share of farmers not applying emission reducing techniques	

Pangaribowo et al. (2013) have identified data sources for some of the indicators. Other indicators have to be derived from individual studies.

5. CONCLUSION AND OUTLOOK

Assessing the status for the EU food system with respect to its various outcomes is a complex undertaking. The SUSFANS team developed an approach to derive a small set of high level performance metrics describing the four SUSFANS policy goals from a much larger number of variables and indicators. The full list of metrics for each goal can be found in Table 11. This approach should allow policy and decision makers concerned with different parts of the whole EU food system to make sense of trends that are becoming visible in the present but also to think about possible innovations to move the EU food system closer towards sustainability and thus in the direction of the four outlined policy goals. These innovation options and possibilities for food system change are explored in more detail in WP5 as well as W6 and WP10. The metrics presented here allows the assessment of these proposed options. That said in this first step to metric selection presented here the current set up of the performance metrics only allows an assessment within each policy goal but not yet with a view across all four goals at the same time.

In a next step, the team is exploring which of the models of the SUSFANS tool box can estimate which ones of the performance metrics. This assessment of the model capabilities will also yield a better understanding of which performance metrics will have to be aggregated and estimated using qualitative methods in addition to describing which linkages across the models might have to be built. Deliverable D1.4 will describe the modelling strategy in more detail.

In a second step the SUSFANS team will bring all performance metrics together in an integrated set that will allow a view across all four policy goals and thus across all aspects of SFNS. The proposed method for doing this will be described in D1.5. To this end, the performance metrics will be presented in form of a spider diagram (Figure 2) showing where the EU currently stands on the selected metrics for all four policy goals. The diagram will also allow a visualisation of the potential impacts of different policy interventions. The aim is to offer the spider diagram in easily-accessible on-line format whereby users can gauge overall impact or access specific areas of interest in greater detail. It will also be possible to examine an entire next level of detail across the spider diagram by clicking on a given performance metrics to expand that section of the diagram and illustrate the indicators, variables and the aggregation pathway. Overall aim of presenting the performance metrics in this way is to give decision makers the option to not only see how a proposed food system innovation (e.g. introduction of insect protein) would fare with respect to achieving a more balanced diet but also what consequences this intervention would for the other policy goals. Thus the diagram could be used to visualize the unintended consequences of an intervention together with the expected outcomes.

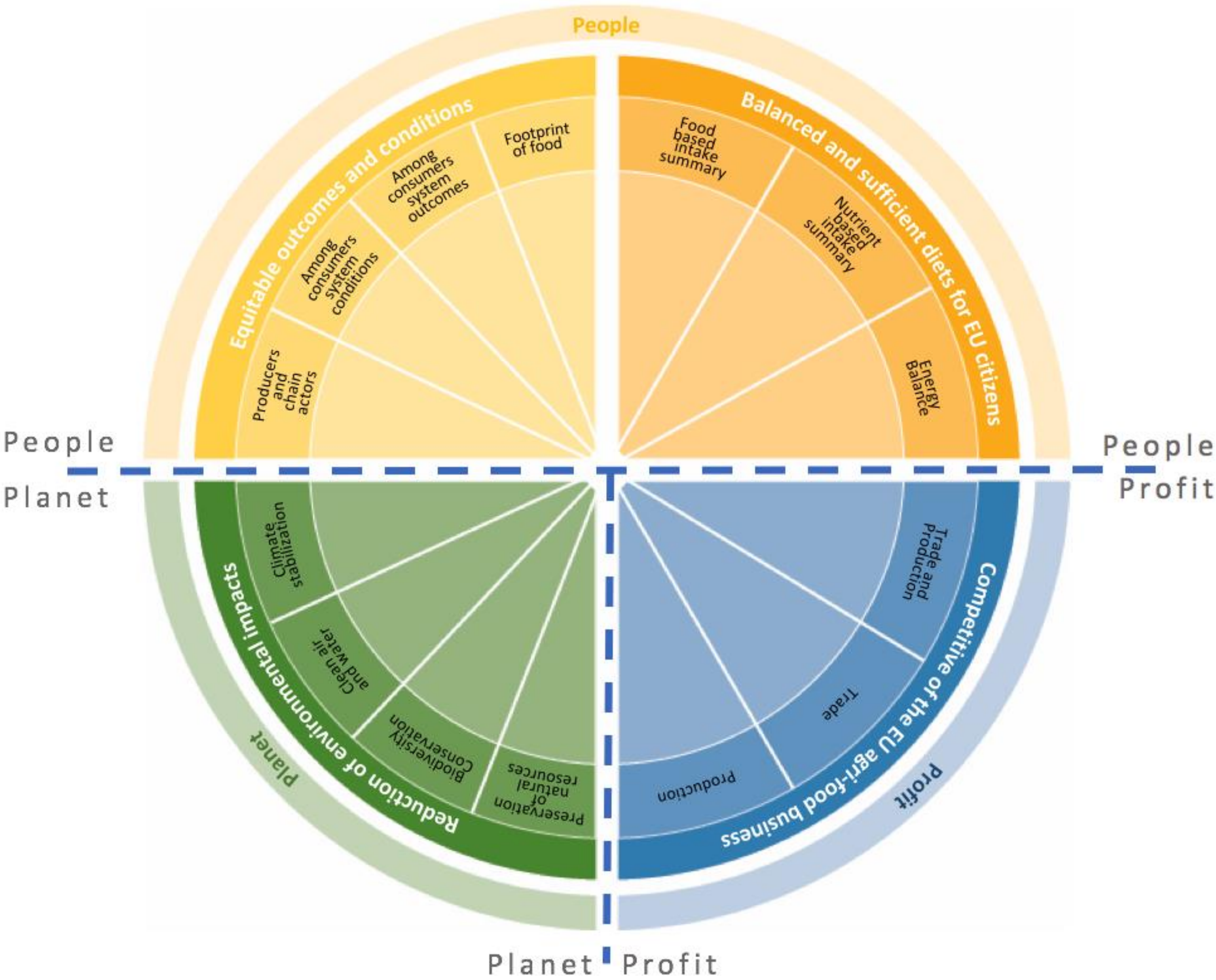

Figure 2 Proposed integrated set of metrics for assessing SFNS *of the EU food system*

In order to make the proposed integration tool, i.e. the spider diagram, as user friendly as possible the project will hold a round of consultations with the SCG of the project. This will be done via a web based survey and a webinar to elicit stakeholder options on how they see the metrics set fitting into their decision making processes. Stakeholders will be also consulted on the current set of Equity metrics as these have been developed only since the last stakeholder meeting.

One challenge that the SUSFANS team will still have to address in the work on the metrics and the integration tool is how different stakeholders or groups of consumer will prioritize the various performance metrics in their decision making processes. Each actor is likely to give a different weighting to the policy goals and thus to the metrics describing these. Also, it is likely that consumer groups across different countries will differ in their priorities with respect to the food system outcomes, e.g.

prioritizing social outcomes over environmental ones. Thus the project team is aiming to find a way how stakeholders can 'play' with the weights given to different metrics.

An additional challenge is to ensure that the integrated metrics tool is flexible enough to allow the integration of new insights from the project's and external work into its metrics hierarchy and also accommodate shifting policy priorities across different stakeholder groups. For the pilot application developed for D1.5 the team will see if these aspects can already be addressed.

Table 11. The complete set of SUSFANS performance metrics and their associated indicators and variables.

POLICY GOALS	Performance metrics (assessable against targets; B derived from C)	Aggregate indicators (C, derived from D)	Derived variable (D, derived from E)		Individual variable (E)
Balanced and sufficient diet for EU citizens'	Food based summary score based on 5 key foods (0-100): • Fruits • Vegetables • Fish • Red & Processed meat intake • Sugar Sweetened Beverages (SSB)	N.A.	Vegetables Legumes (Unsalted) nuts and seeds Fruits Fish	Dairy Red/ processed meat Hard cheese Sugar sweetened beverages Alcohol Salt	Intake of >10 food products have been individually assessed in country specific population surveys and have been aligned with FoodEx2 classification system

	Nutrient based summary score (0-100) • NRD 9.3 • NRD 15.3	N.A.	**NRD 9.3** includes protein, dietary fibre, calcium, iron, potassium, magnesium, and vitamin A, C and E, saturated fat, added sugar, and sodium. **NRD 15.3** additionally includes mono-unsaturated fatty acids, zinc, vitamin D and B-vitamins (B1, B2, B12, folate), but excludes magnesium.	Energy Protein Mono-unsaturated fat Fibre Calcium Iron Magnesium Potassium Selenium Iodine Zinc Vitamin A Vitamin C Vitamin E Vitamin B1 Vitamin B2 Vitamin B6 Vitamin B12 Folate Vitamin D Sodium Saturated fat Total sugar Protein, plant Protein, animal Saturated Fatty Acids (SFA) Mono-Unsaturated Fatty Acids (MUFA) Poly-Unsaturated Fatty Acids (PUFA)
	Energy balance % of population with normal weight: 100% is 'ideal'		BMI (kg/m2): normal weight: 18.5–24.9 overweight: 25–29.9 obese:>30 kg/m2	BMI (body mass index of each country)
Reduction of environmental impacts	Climate stabilization	Reduction of total GHG emissions caused by the agri-food chain	CO2 eq	CO2, CH4, N2O (Emissions according to IPCC categories incl. indirect land use change, per unit of product in food consumed (LCA) = C footprints)
				Use/emissions of cooling agents in fish production (CFCs, …)
			Radiative Forcing	Land Cover (e.g. albedo)

	Clean air and water	Reduction of N surplus	Nitrogen surplus	N input (fertiliser, manure, atmospheric deposition, biological fixation, feed) and N output (yield), change of soil stocks. Maybe split of N surplus into emissions to the atmosphere: air pollution and emissions to the hydrosphere: water pollution)
		Reduction of N emissions to the atmosphere (air pollution)	Emissions of Nr to the atmosphere (NH3, NOx)	Emissions of NH3, NOx
		Reduction of N emissions to the hydrosphere (water pollution)	Emissions of Nr to the hydrosphere (Nitrates, Organic N)	Emissions of NH3, NOx Emissions of NO3, other run-off, leaching
		Reduction of P surplus	Phosphorus surplus	P input and output
		Reduction of Toxic substances use	Toxic substances use	Use of toxic substances (pesticides, ...)
	Biodiversity conservation	Reduction of the contribution of the agrifood chain to loss of Mean Species Abundance (MSA)	Contribution to loss of Mean Species Abundance (MSA) calculated with the GLOBIO model (Alkemade et al., 2009)	Land use
				Emissions of GHGs, Nr
		Land use	Land use (Shannon)	The Shannon's entropy index (Hr)
				seafloor area impacted (m2)
			Protected areas (GLOBIOM)	Land use map
			Species rich hotspots (GLOBIOM)	Land use map
		Reduction in number of threatened species	Red List Index (RLI)	IUCN Red List threat status (terrestrial and marine) of affected species
	Preservation of natural resources	Sustainable water use [e.g. maintenance of environmental flows]	Terrestrial water scarcity footprint	Irrigation water use
				Water use in livestock production
				Water use in the food chain
				Water supply
		Sustainable exploitation of wild-caught seafood resources	distance to optimum exploitation (F/FMSY)	Fishing mortality (F)

			%PPR relative to total available ecosystem production	primary production required (PPR)
		Maintenance of soil fertility	Soil degradation	Erosion
				Soil carbon contents
Competitiveness of EU agri-food business	Production and trade	Difference of the **openness of country** i between period t2 and t1 of sector k. Unit % (C1)	**Openness of country** i for sector k. Unit: % (D1)	x_{ijkt}, m_{ijkt}, GP_{ikt},
		Difference of the Self-sufficiency ratio of country i between period t2 and t1 of sector k. Unit % (C2)	**Self–Sufficiency ratio** of the country i for sector k. Unit: % (D2)	
	Trade - Export flow orientation	**Growth export share on the world market** for sector k for country i between period t2 and t1. No unit (C3)	**Export share of country** i of sector k to the world (w) in year t. No unit (D3)	x_{ijkt}, x_{iwkt}, m_{iwkt}, ${}_{x}T_{iwt}$, X_{kt}, XT_{wt}, ${}_{m}T_{iwt}$, MT_{wt},
	Trade - Trade orientation		**Trade balance** of country i in period t is the sum of export minus all imports of sector k. Unit: USD (D4)	
		Difference of the normalized trade balance of country i between period t2 and t1 of sector k. No unit. (C5)	Normalized trade balance of country i in period t is the sum of export minus all imports of sector k. No unit. (D5)	
	Trade - Trade specialization	**Growth RXA on the world market** for sector k for country i between period t2 and t1. No unit (C6)	**Revealed Comparative Export Advantage** (RXA) indicator for sector k, country i in period t. No unit. (D6)	
			Revealed Comparative Import Advantage (RMA) indicator for sector k, country i in period t. No unit. (D7)	
		Growth RTA of sector k for country i between period t2 and t1. No unit. (C8)	**Revealed Net Trade Advantage (**RTA) indicator for sector k, country i in period t. No unit. (D8)	
	Production - Economic performance of a sector	Growth RVA of sector k for country i between period t2 and t1. No unit. (C9)	**Real value added** for sector k in in country i for period t. Unit: USD (D9)	GVA_{ikt}, PI_{it}, GP_{ikt}, V_{aikt}, E_{ikt}, GVA_{ibt}, GP_{ibt}, VA_{ibt}, E_{ibt}
		Relative growth total factor productivity for sector k in in country i for period t (C10)	**Total factor productivity** for sector k in in country i for period t (D10)	

		Relative growth real labour productivity for sector k in in country i for period t. Unit: USD VA per USD E (C11)	Real labour productivity for sector k in in country i for period t. Unit: USD VA per USD E (D11)	
	Production - Productivity cross-sector benchmarking	Relative growth ratio real value added for sector k in in country i for period t (C12)	Ratio real value added for sector k in benchmark sector b in country i for period t (D12)	
		Relative growth ratio total factor productivity for sector k in in country i for period t (C13)	Ratio real **total factor productivity** for sector k in benchmark sector b in country i for period t (D13)	
		Relative growth ratio real labour productivity for sector k in in country i for period t (C14)	Ratio real labour productivity k in benchmark sector b in country i for period t (D14)	
Equitable outcomes and conditions	Equity among consumers: food system outcomes	Availability	Calorie availability by region (EU, non-EU)	MAGNET
			Share of nutritious food by region (EU, non-EU)	MAGNET
			Reduction in share of protein of animal origin by region (EU, non-EU)	MAGNET
			Domestic food production per capita by region (EU, non-EU)	MAGNET
		Accessibility	Share of food expenditure in total expenditures by region (EU, non-EU)	MAGNET
			Food affordability by region (EU, non-EU)	MAGNET
			Consumption per capita by region (EU, non-EU)	MAGNET
		Utilization	Share of calories from fruit and vegetables by region (EU, non-EU)	MAGNET
		Stability	Cereal import dependency ratio by region (EU, non-EU)	MAGNET
			Value of food imports over total merchandise exports by region (EU, non-EU)	MAGNET
			Market pressure index	AgriPrice

		Health: Undernutrition	Share of population with BMI <18.5	
			Share of children < 5 years with stunting	WHO/UNICEF
			Share of children < 5 years with iron deficiency	WHO/UNICEF
			Share of children < 5 years with vitamin A deficiency	WHO/UNICEF
			Share of women at reproductive age with iron deficiency	WHO/UNICEF
			Share of women at reproductive age with vitamin A deficiency	WHO/UNICEF
			Share of population with insufficient dietary supply adequacy	FAO
			Share of population with insufficient protein supply	FAO
		Health: Overweight and obesity	Share of population with BMI >25	
			Share of population with BMI >30	
	Equity among consumers: food system conditions	Wealth	National income per capita by region as % of EU national income per capita	MAGNET
			Household income per capita by region as % of EU household income per capita	MAGNET
			Share of population with less than 1$ a day	World Bank
			Share of population that has no access to a health care centre	World Bank
			Share of population without access to sanitation facilities	World Bank
			Share of female population without primary education	
		Political stability	Share of population living in a political unstable surrounding	
			Share of population without right to social security	FAO

			Share of population that has no access to a safety net (food assistance, pension)	
		Consumer choices	Share of population without access to a fresh food shop	
			Share of population whose food preferences are not met by food supply	
	Equity among producers and chain actors	Access to resources by primary producers	Share of farmers without legal status of ownership of the farm land	
			Share of farm women without access to agricultural land	
		Access to finance and technology	Share of farmers without access to microfinance	World Bank
			Share of farm women without access to saving and credit	World Bank
			Share of farmers without primary education	
			Share of farmers without access to vocational training	
		Producer sovereignty	Share of farmers who are faced with a monopolist downstream industry	
			Share of farmers who are faced with a monopolist upstream industry	
	Equity in food footprint	Resources embedded in and emissions related to food consumption	Ha of land per calorie consumed	MAGNET
			Kg of fertilizer per calorie consumed	MAGNET
			Litre of water per calorie consumed	
			Unit of emissions per calorie consumed	
		Resources embedded in and emissions related to food production	Share of farmers applying no organic production methods	
			Share of farmers without education in the use of pesticides and fertilizers	
			Share of farmers not applying emission reducing techniques	

REFERENCES

'Alkama, R. and A. Cescatti (2016). "Biophysical climate impacts of recent changes in global forest cover." Science 351(6273): 600-604.

Ablove, T, et al. (2015) Body mass index continues to accurately predict percent body fat as women age despite changes in muscle mass and height. Menopause, 22(7): p. 727-30.

Acharya, T., J. Fanzo, D. Gustafson, J. Ingram, B. Schneeman, L. Allen, K. Boote, A. Drewnowski, F. Ewert and S. Hall (2014). "Assessing sustainable nutrition security: the role of food systems." Center for Integrated Modeling of Sustainable Agriculture and Nutrition Security. Washington, DC.

Alkemade, R., M. Oorschot, L. Miles, C. Nellemann, M. Bakkenes and B. ten Brink (2009). "GLOBIO3: A Framework to Investigate Options for Reducing Global Terrestrial Biodiversity Loss." Ecosystems 12(3): 374-390.

Allen, T. and P. Prosperi (2014). "Metrics of Sustainable Diets and Food Systems. Workshop Report. Bioversity International & CIHEAM-IAMM. Montpellier, France.".

Allen, T., P. Prosperi, B. Cogill and G. Flichman (2014). "Agricultural biodiversity, social-ecological systems and sustainable diets." Proceedings of the Nutrition Society **73**: 498-508.

Balassa, B. (1965). "Trade liberalisation and "revealed" comparative advantage." The Manchester School **33**(2): 99-123.

Ballard, T. J., A. W. Kepple and C. Cafiero (2013). "The food insecurity experience scale: development of a global standard for monitoring hunger worldwide. Technical Paper. Rome, FAO. Retrieved from: http://www.fao.org/economic/ess/ess-fs/voices/en/."

Bradbury, KE, et al. (2017) Association between physical activity and body fat percentage, with adjustment for BMI: a large cross-sectional analysis of UK Biobank. BMJ Open, 7(3): p. e011843.

Buckley, P. J., C. L. Pass and K. Prescott (1988). "Measures of international competitiveness: A critical survey." Journal of marketing management **4**(2): 175-200.

Butchart, S. H. M., A. J. Stattersfield, J. Baillie, L. A. Bennun, S. N. Stuart, H. R. Akcakaya, C. Hilton-Taylor and G. M. Mace (2005). "Using Red List Indices to measure progress towards the 2010 target and beyond." Philosophical Transactions of the Royal Society B: Biological Sciences 360(1454): 255-268.

Butchart, S. H. M., M. Walpole, B. Collen, A. van Strien, J. P. W. Scharlemann, R. E. A. Almond, J. E. M. Baillie, B. Bomhard, C. Brown, J. Bruno, K. E. Carpenter, G. M. Carr, J. Chanson, A. M. Chenery, J. Csirke, N. C. Davidson, F. Dentener, M. Foster, A. Galli, J. N. Galloway, P. Genovesi, R. D. Gregory, M. Hockings, V. Kapos, J. F. Lamarque, F. Leverington, J. Loh, M. A. McGeoch, L. McRae, A. Minasyan, M. H. Morcillo, T. E. E. Oldfield, D. Pauly, S. Quader, C. Revenga, J. R. Sauer, B. Skolnik, D. Spear, D. Stanwell-Smith, S. N. Stuart, A. Symes, M. Tierney, T. D. Tyrrell, J. C. Vie and R. Watson (2010). "Global Biodiversity: Indicators of Recent Declines." Science 328(5982): 1164-1168.

Čapková, N, Lustigová, M, Kratěnová, J, Žejglicová, K (2016): (in Czech) Zdravotní stav české populace – výsledky studie EHES. Státní zdravotní ústav, 2016, 32 s. ISBN 978-80-7071-356-3.

Carlton, D. W. and J. M. Perloff (1999). Modem industrial organization. Reading, Massachusetts, Addison-Wesley.

Carraresi, L. and A. Banterle (2015). "Agri-food Competitive Performance in EU Countries: A Fifteen-Year Retrospective." International Food and Agribusiness Management Review **18**(2): 37.

CFS. (2012). "Coming to Terms with Terminology: Food Security, Nutrition Security, Food Security and Nutrition, Food and Nutrition Security." Thirty-ninth Session Retrieved 4 August, 2016, from http://www.fao.org/docrep/meeting/026/MD776E.pdf.

Christensen, V., S. Guenette, J. J. Heymans, C. J. Walters, R. Watson, D. Zeller and D. Pauly (2003). "Hundred-year decline of North Atlantic predatory fishes." Fish and Fisheries 4(1): 1-24.

Clapp, J. (2014). "Food security and food sovereignty: Getting past the binary." Dialogues in Human Geography **4**(2): 206-211.

Coll, M., S. Libralato, S. Tudela, I. Palomera and F. Pranovi (2008). "Ecosystem Overfishing in the Ocean." PLoS ONE 3(12): e3881-e3881.

Crouch, G. I. and J. B. Ritchie (1999). "Tourism, competitiveness, and societal prosperity." Journal of business research **44**(3): 137-152.

Cuaresma, Jesus Crespo, Jaroslava Hlouskova, and Michael Obersteiner. "Forecasting Commodity Prices Under Specification Uncertainty: A Comprehensive Approach." SUSFANS Deliverable D8.3, 2017. http://www.susfans.org/portfolio/deliverable-83-forecasting-commodity-prices-under-specification-uncertainty-comprehensive

De Bakker, Erik, Michiel van der Werff, Michiel van Dijk, Thom Achterbosch. "Shifting governance visions on global food and nutrition security: Lessons from the FOODSECURE stakeholder scenario approach." FOODSECURE working paper no. 59. The Hague: LEI Wageningen UR. May 2017

De Vries, W., J. Kros, G. J. Reinds and K. Butterbach-Bahl (2011). "Quantifying impacts of nitrogen use in European agriculture on global warming potential." Current Opinion in Environmental Sustainability 3(5): 291-302.

Diana, J. S. (2009). "Aquaculture Production and Biodiversity Conservation." BioScience 59(1): 27-38.

Dise, N. B., M. Ashmore, S. Belyazid, A. Bleeker, R. Bobbink, W. de Vries, J. W. Erisman, T. Spranger, C. J. Stevensand and L. van den Berg (2011). Nitrogen as a threat to European terrestrial biodiversity. M. Sutton, C. Howard, J. W. Erisman et al. Cambridge, Cambridge University Press. 333: 463-494.

Drewnowski, A (2005). Concept of a nutritious food: toward a nutrient density score." The American J Clin Nutr 82(4): 721-732.

Drewnowski, A (2009). Defining nutrient density: development and validation of the nutrient rich foods index." Journal of the American College of Nutrition 28(4): 421S-426S.

Drury, C. M. (2013). Management and cost accounting, Springer.

Dulvy, N. K., Y. Sadovy and J. D. Reynolds (2003). "Extinction vulnerability in marine populations." Fish and Fisheries 4(1): 25-64.

Durand, M., J. Simon and C. Webb (1992). "OECD's indicators of international trade and competitiveness."

Ec (1991). "Council Directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC)."

Ec (2001). "Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on national emission ceilings fo rcertain atmospheric pollutants." Official Journal of the European Communities 2001L0081(October 2001): 22-30.

Eea (2015). Annual European Union greenhouse gas inventory 1990–2013 and inventory report 2015. EEA Technical report No. 19/2015. Luxembourg, Publications Office of the European Union.

EFSA - European Food Safety Authority (2010). Scientific Opinion on principles for deriving and applying Dietary Reference Values. EFSA Journal 2010 8(3): 1458.

EFSA - European Food Safety Authority (2014). Guidance on the EU Menu methodology. EFSA Journal 2014;12(12):3944

Emeis, K.-C., J. van Beusekom, U. Callies, R. Ebinghaus, A. Kannen, G. Kraus, I. Kröncke, H. Lenhart, I. Lorkowski, V. Matthias, C. Möllmann, J. Pätsch, M. Scharfe, H. Thomas, R. Weisse and E. Zorita (2015). "The North Sea — A shelf sea in the Anthropocene." Journal of Marine Systems 141: 18-33.

Eu (2000). "Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy." Official Journal of European Union L327.

Eu (2008). "Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) (Text with EEA relevance)." Official Journal of European Union L164.

Eu (2013). "Regulation (EU) No 1305/2013 of the European Parliament and of the Council of 17 December 2013 on support for rural develoment by the European Agricultural Fund for Rural Development (EAFRD) and repealing Council Regulation (EC) No 1698/2005." Official Journal of the European Union L 347: 487-548.

Eu (2013). "Regulation (EU) No 1306/2013 of the European Parliament and of the Council of 17 December 2013 on the financing, management and monitoring of the common agricultural policy and repealing Council Regulations (EEC) No 352/78, (EC) No 165/94, (EC) No 2799/98." Official Journal of the European Union L 347: 549-607.

Eu (2013). "Regulation (EU) No 1307/2013 of the European Parliament and of the Council of 17 December 2013 establishing rules for direct payments to farmers under support schemes within the framework of the common agricultural policy and repealing Council Regulation." Official Journal of the European Union L 347: 608-670.

Eu (2014). Facts and figures on the Common Fisheries Policy. Basic statistical data. 2014 Edition.

Eu (2016). "Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC (Text with EEA relevance." Official Journal of European Union L344.

European, C. (2011). "COM(2011)112 final. Communication from the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A Roadmap for moving to a competitive low carbon economy in 2050." Official Journal of European Union.

European, C. (2011). "COM/2011/0244 final. Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions: Our life insurance, our natural capital: an EU biodiversity strategy to 2020." (2011): 17-17.

European, C. (2013). Communication from the Commission to the European Parliament, the Council, the European Economic and Social committee and the Committee of the Regions. A Clean Air Programme for Europe.

European, C. (2014). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A policy framework for climate and energy in the period from 2020 to 2030. COM(2014) 15 final.

European, U. (2015). "Council Decision (EU) 2015/1339 of 13 July 2015 on the conclusion, on behalf of the European Union, of the Doha Amendment to the Kyoto Protocol to the United Nations Framework Convention on Climate Change and the joint fulfilment of commitments thereunder." Official Journal of the European Union L2017.

European#Council (2000). Presidency conclusions, Lisbon European Council. 23 and 24 march 2000.

FAO (2015). The state of food insecurity in the world 2015. Rome.

FAO (2016). Food security indicators.

Fao (2016). The State of World Fisheries and Aquaculture 2016. Rome, Food and Agriculture Organization of the United Nations.

FAO. (2016). "FAO Statistical Pocket Book." Retrieved 21-06-2016, 2016, from http://www.fao.org/docrep/016/i2493e/i2493e06.pdf.

Fertö, I. and L. J. Hubbard (2003). "Revealed Comparative Advantage and Competitiveness in Hungarian Agri–Food Sectors." The World Economy **26**(2): 247–259.

Fischer, C. (2010). "Food quality and product export performance: an empirical investigation of the EU situation." Journal of International Food & Agribusiness Marketing **22**(3-4): 210-233.

Fischer, C. G. and T. Garnett (2016). "Plates, pyramids and planets: Developments in national healthy and sustainable dietary guidelines: a state of play assessment. FAO and The Food Climate Research Network at The University of Oxford.".

Flegal, K.M., et al., Comparisons of percentage body fat, body mass index, waist circumference, and waist-stature ratio in adults. Am J Clin Nutr, 2009. 89(2): p. 500-8.

Fleisher, C. S. and B. E. Bensoussan (2003). Strategic and competitive analysis: methods and techniques for analyzing business competition, Prentice Hall Upper Saddle River, NJ.

Friel, S. and P. I. Baker (2009). "Equity, food security and health equity in the Asia Pacific region." Asia Pac J Clin Nutr 18(4): 620-632.

Frohberg, K. and M. Hartmann (1997). Comparing measures of competitveness. Halle, Institute of Agricultural Development in Central and Eastern Europe.

Fulgoni VL, Keast DR, Drewnowski A (2009) Development and validation of the nutrient-rich foods index: a tool to measure nutritional quality of foods. J Nutr. Aug;139:1549-54.

Garnier, J., A. Beusen, V. Thieu, G. Billen and L. Bouwman (2010). "N:P:Si nutrient export ratios and ecological consequences in coastal seas evaluated by the ICEP approach." Global Biogeochemical Cycles 24: GB0A05-GB00A05.

Global Panel (2015). "Improved metrics and data are needed for effective food system policies in the post-2015 era. Technical Brief. London, UK. Global Panel on Agriculture and Food Systems for Nutrition.".

Gorton, M., C. Hubbard and I. Fertő (2013). Theoretical background and conceptual framework. Halle, Leibniz Institute of Agricultural Development in Transition Economies (IAMO).

Grizzetti, B., F. Bouraoui and A. Aloe (2012). "Changes of nitrogen and phosphorus loads to European seas." Global Change Biology 18(2): 769-782.

Grizzetti, B., F. Bouraoui, G. Billen, H. van Grinsven, A. C. Cardoso, V. Thieu, J. Garnier, C. Curtis, R. W. Howarth and P. J. Johnes (2011). Nitrogen as a threat to European water quality. M. Sutton, C. Howard, J. W. Erisman et al. Cambridge, Cambridge University Press: 379-404.

Gudmundsson, H. (2003). "The Policy Use of Environmental Indicators - Learning from Evaluation Research." The Journal of Transdisciplinary Environmental Studies **2**(2): 1-12.

Gustafson, D., A. Gutman, W. Leet, A. Drewnowski, J. Fanzo and J. Ingram (2016). "Seven food system metrics of sustainable nutrition security." Sustainability **8**(3): 1-17.

Halpern, B. S., C. Longo, J. S. S. Lowndes, B. D. Best, M. Frazier, S. K. Katona, K. M. Kleisner, A. A. Rosenberg, C. Scarborough and E. R. Selig (2015). "Patterns and Emerging Trends in Global Ocean Health." PLOS ONE 10(3): e0117863-e0117863.

Hamel, G. and C. K. Prahalad (1994). Competing for the future: Breakthrough strategies for seizing control of your industries and creating the markets of tomorrow. Harvard, Harvard Business School Press.

Hansen, J., M. Sato, P. Kharecha, D. Beerling, R. Berner, V. Masson-Delmotte, M. Pagani, M. Raymo, D. L. Royer and J. C. Zachos (2008). "Target Atmospheric CO2: Where Should Humanity Aim?" The Open Atmospheric Science Journal 2(1): 217-231.

Hebinck, A. and Villarreal G. (2016) 'Local' level analysis of FNS pathways the Netherlands. Exploring two case studies: Urban Food Initiatives and Food Bank practices. Wageningen University, TRANSMANGO project. http://transmango.eu/userfiles/update%2009112016/reports/5%20the%20netherlands%20report.pdf.

Henderson, A. (2015). Eutrophication. M. Z. Hauschild and M. A. J. Huijbregts. Dordrecht, Springer Netherlands: 177-196.

Hoekstra, A. Y., A. K. Chapagain, M. M. Aldaya and M. M. Mekonnen (2011). The Water Footprint Assessment Manual. Setting the global standard. London, earthscan.

Howarth, L. M., C. M. Roberts, R. H. Thurstan and B. D. Stewart (2014). "The unintended consequences of simplifying the sea: making the case for complexity." Fish and Fisheries 15(4): 690-711.

Ingram, J. (2011). "A food systems approach to researching food security and its interactions with global environmental change." Food Security **3**(4): 417-431.

Ipcc (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme - Volume 4 Agriculture, Forestry and Other Land Use. Japan, IGES.

Ipcc (2014). "Climate Change 2014 Synthesis Report Summary Chapter for Policymakers." Ipcc: 31-31.

Jambor, A. and S. Babu (2016). Competitiveness: Definitions, Theories and Measurement. Competitiveness of Global Agriculture, Springer**:** 25-45.

Kram, T. and E. Stehfest (2012). The IMAGE model suite used for the OECD Environmental Outlook to 2050. Bilthoven, PBL Netherlands Environmental Assessment Agency.

Krugman, P. (1994). "Competitiveness: a dangerous obsession." FOREIGN AFFAIRS-NEW YORK- **73**: 28-28.

Krugman, P. R. and M. Obstfeld (2006). International Economics: Theory and Policy. Boston, Pearson/Addison-Wesley.

Kalkuhl, Matthias, Joachim von Braun, and Maximo Torero, eds. *Food Price Volatility and Its Implications for Food Security and Policy*. Cham: Springer Open, 2016.

Lal, R. (2016). "Beyond COP 21: Potential and challenges of the "4 per Thousand" initiative." Journal of Soil and Water Conservation 71(1): 20A-25A.

Latruffe, L. (2010). Competitiveness, Productivity and Efficiency in the Agricultural and Agri-Food Sectors", OECD Food, Agriculture and Fisheries Working Papers No. 30. Paris, OECD Publishing.

Le Vallée, J.-C. and M. Grant (2016). "Canada's Food Report Card 2015: International Comparison. Ottowa: The Conference Board of Canada, 2016."

Lehtonen, M. (2015). Indicators: tools for informing, monitoring or controlling? The Tools of Policy Formulation: Actors, Capacities, Venues and Effects. A. J. Jordan and J. R. Turnpenny, Edward Elgar Publishing Ltd.

Lehtonen, M., L. Sébastien and T. Bauler (2016). "The multiple roles of sustainability indicators in informational governance: between intended use and unanticipated influence." Current Opinion in Environmental Sustainability **18**: 1-9.

Leip, A., B. Achermann, G. Billen, A. Bleeker, A. Bouwman, W. de Vries, U. Dragosits, U. Doring, D. Fernall, M. Geupel, J. Herolstab, P. Johnes, L. Gall, A. Christine, S. Monni, R. Neveceral, L. Orlandini, M. Prud'homme, H. Reuter, D. Simpson, G. Seufert, T. Spranger, M. Sutton, J. van Aardenne, M. Voss and W. Winiwarter (2011). "Integrating nitrogen fluxes at the European scale." The European Nitrogen Assessment 5(2009): 345-376.

Leip, A., G. Billen, J. Garnier, B. Grizzetti, L. Lassaletta, S. Reis, D. Simpson, M. a. Sutton, W. de Vries, F. Weiss and H. Westhoek (2015). "Impacts of European livestock production: nitrogen, sulphur, phosphorus and greenhouse gas emissions, land-use, water eutrophication and biodiversity." Environmental Research Letters 10(11): 115004-115004.

Leip, A., M. Bielza, C. Bulgheroni, P. Ciaian, M. Lamboni, M.-l. Paracchini, J.-m. Terres, F. Weiss and H.-p. Witzke Spatially Explicit Evaluation of the Agri - environmental Impact of CAP.

Lenzen, M., D. Moran, K. Kanemoto, B. Foran, L. Lobefaro and A. Geschke (2012). "International trade drives biodiversity threats in developing nations." Nature 486(7401): 109-112.

Lewison, R., L. Crowder, A. Read and S. Freeman (2004). "Understanding impacts of fisheries bycatch on marine megafauna." Trends in Ecology & Evolution 19(11): 598-604.

Lukas, M., H. Rohn, M. Lettenmeier, C. Liedtke and K. Wiesen (2016). "The nutritional footprint - integrated methodology using environmental and health indicators to indicate potential for absolute reduction of natural resource use in the field of food and nutrition." Journal of Cleaner Production **132**: 161-170.

Mace (2001). "A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management." Fish and Fisheries 2(1): 2-32.

Maes, J., C. Liquete, A. Teller, M. Erhard, M. L. Paracchini, J. I. Barredo, B. Grizzetti, A. Cardoso, F. Somma, J.-E. Petersen, A. Meiner, E. R. Gelabert, N. Zal, P. Kristensen, A. Bastrup-Birk, K. Biala, C. Piroddi, B. Egoh, P. Degeorges, C. Fiorina, F. Santos-Martín, V. Naruševičius, J. Verboven, H. M. Pereira, J. Bengtsson, K. Gocheva, C. Marta-Pedroso, T. Snäll, C. Estreguil, J. San-Miguel-Ayanz, M. Pérez-Soba, A. Grêt-Regamey, A. I. Lillebø, D. A. Malak, S. Condé, J. Moen, B. Czúcz, E. G. Drakou, G. Zulian and C. Lavalle (2016). "An indicator framework for assessing ecosystem services in support of the EU Biodiversity Strategy to 2020." Ecosystem Services 17: 14-23.

Maggio, A., T. Van Cricking and J. P. Malingreau (2015). "Global Food Security 2030: assessing trends with a view to guiding future EU policies." Joint Research Centre Foresight and Behavioural Insights Unit, Science and Policy Reports.

Marchal, P., J. L. Andersen, M. Aranda, M. Fitzpatrick, L. Goti, O. Guyader, G. Haraldsson, A. Hatcher, T. J. Hegland, P. Le Floc'h, C. Macher, L. Malvarosa, C. D. Maravelias, S. Mardle, A. Murillas, J. R. Nielsen, R. Sabatella, A. D. M. Smith, K. Stokes, T. Thoegersen and C. Ulrich (2016). "A comparative review of fisheries management experiences in the European Union and in other countries worldwide: Iceland, Australia, and New Zealand." Fish and Fisheries 17(3): 803-824.

Marsh, I. W. and S. Tokarick (1994). "Competitiveness indicators: a theoretical and empirical assessment."

Mekonnen, M. M. and a. Y. Hoekstra (2011). "The green, blue and grey water footprint of crops and derived crop products." Hydrology and Earth System Sciences 15(5): 1577-1600.

Metcalfe, J. S., L. Georghiou, P. Cunningham and H. M. Cameron (1992). Evaluation of the impact of European Community research programmes upon the competitiveness of European industry-Concepts and approaches. EUR 14198 EN. Research evaluation. Science and Technology Policy Series.

Mikic, M. and J. Gilbert (2009). Trade Statistics in Policymaking-A handbook of commonly used trade indices and indicators.

Mozaffarian, D. and D.S. Ludwig, Dietary guidelines in the 21st century--a time for food. JAMA, 2010. 304(6): p. 681-2.

Mulvany, P. and J. Ensor (2011). "Changing a dysfunctional food system: Towards ecological food provision in the framework of food sovereignty." Food chain 1(1).

O'Mahoney, M. and B. van#Ark (2003). EU-productivity and competitiveness: an industry perspective. Luxembourg, Office for Official Publication of the European Community**:** 273.

Pangaribowo, E., N. Gerber and M. Torero (2013). Food and Nutrition Security Indicators: A Review, LEI Wageningen UR.

Pelletier, N. and A. Leip (2014). "Quantifying anthropogenic mobilization, flows (in product systems) and emissions of fixed nitrogen in process-based environmental life cycle assessment: rationale, methods and application to a life cycle inventory." The International Journal of Life Cycle Assessment 19(1): 166-173.

Pfister, S. and P. Bayer (2014). "Monthly water stress: spatially and temporally explicit consumptive water footprint of global crop production." Journal of Cleaner Production 73: 52-62.

Pinsky, M. L., O. P. Jensen, D. Ricard and S. R. Palumbi (2011). "Unexpected patterns of fisheries collapse in the world's oceans." Proceedings of the National Academy of Sciences 108(20): 8317-8322.

Pinstrup-andersen, P. (2009). "Food security : definition and measurement." Food Security **1**: 5-7.

Popp, A., K. Calvin, S. Fujimori, P. Havlik, F. Humpenöder, E. Stehfest, B. L. Bodirsky, J. P. Dietrich, J. C. Doelmann, M. Gusti, T. Hasegawa, P. Kyle, M. Obersteiner, A. Tabeau, K. Takahashi, H. Valin, S. Waldhoff, I. Weindl, M. Wise, E. Kriegler, H. Lotze-Campen, O. Fricko, K. Riahi and D. P. v. Vuuren (2017). "Land-use futures in the shared socio-economic pathways." Global Environmental Change 42: 331-345.

Porter, M. E. (1980). Competitive strategy: Techniques for Analyzing Industries and Competitiors. New York, The Free Press.

Porter, M. E. (1990). The competitive advantage of nations. London, The MacMillam Press Ltd.

Prosperi, P., T. Allen, M. Padilla, I. Peri and B. Cogill (2014). "Sustainability and Food & Nutrition Security: A Vulnerability Assessment Framework for the Mediterranean Region." SAGE Open **4**(2).

Ranasinghe, C., et al., Relationship between Body Mass Index (BMI) and body fat percentage, estimated by bioelectrical impedance, in a group of Sri Lankan adults: a cross sectional study. BMC Public Health, 2013. 13: p. 797.

Ranganathan, J., D. Vennard, R. Waite, P. Dumas, B. Lipinski and T. Searchinger (2016). "Shifting diets for a sustainable food future. World Resources Institute. Installment 11 of “Creating a Sustainable Food Future”."

Redding, M. R., R. Lewis, T. Kearton and O. Smith (2016). "Manure and sorbent fertilisers increase on-going nutrient availability relative to conventional fertilisers." Science of The Total Environment 569-570: 927-936.

Reid, R. S., C. Bedelian, M. Y. Said, R. L. Kruska, R. M. Mauricio, V. Castel, J. Olson and P. K. Thornton (2010). Global Livestock Impacts on Biodiversity. H. Steinfeld, H. A. Mooney, F. Schneider and L. E. Neville. Washington DC, Scientific Committee on Problems of the Environment (SCOPE); Island Press: 111-137.

Rockström, J., W. Steffen, K. Noone, Å. Persson, F. S. Chapin, E. Lambin, T. M. Lenton, M. Scheffer, C. Folke, H. J. Schellnhuber, B. Nykvist, C. A. de Wit, T. Hughes, S. van der Leeuw, H. Rodhe, S. Sörlin, P. K. Snyder, R. Costanza, U. Svedin, M. Falkenmark, L. Karlberg, R. W. Corell, V. J. Fabry, J. Hansen, B. Walker, D. Liverman, K. Richardson, P. Crutzen and J. Foley (2009). "Planetary boundaries: Exploring the safe operating space for humanity." Ecology and Society 14(2).

Rogelj, J., M. den Elzen, N. Höhne, T. Fransen, H. Fekete, H. Winkler, R. Schaeffer, F. Sha, K. Riahi and M. Meinshausen (2016). "Paris Agreement climate proposals need a boost to keep warming well below 2 °C." Nature 534(7609): 631-639.

Röös, E., et al. (2015). "Evaluating the sustainability of diets–combining environmental and nutritional aspects." Environmental Science & Policy 47: 157-166.

Rosenström, U. and J. Lyytimäki (2006). "The role of indicators in improving timeliness of international environmental reports." European Environment **16**(1): 32-44.

Sagheer, S., S. S. Yadav and S. G. Deshmukh (2009). "Developing a conceptual framework for assessing competitiveness of India's agrifood chain." International Journal of Emerging Markets **4**(2): 137-159.

Schewe, J., J. Heinke, D. Gerten, I. Haddeland, N. W. Arnell, D. B. Clark, R. Dankers, S. Eisner, B. M. Fekete, F. J. Colón-González, S. N. Gosling, H. Kim, X. Liu, Y. Masaki, F. T. Portmann, Y. Satoh, T. Stacke, Q. Tang, Y. Wada, D. Wisser, T. Albrecht, K. Frieler, F. Piontek, L. Warszawski and P. Kabat (2014). "Multimodel assessment of water scarcity under climate change." Proceedings of the National Academy of Sciences 111(9): 3245-3250.

Schwab, K. (2014). The Global Competitiveness Report 2014–2015. Geneva, World Economic Forum.

Scott, L. and T. Vollrath (1992). Global Competitive Advantages and Overall Bilateral Complementarity in Agriculture: A Statistical Review. Washington, Economic Research Service,U.S. Department of Agriculture.

Sen, A. (1981). Poverty and Famines: An Essay on Entitlement and Deprivation, Oxford: Clarendon Press, New York: Oxford.

Shutes, L., H. Valin, E. Stehfest, M. v. Dijk, M. Kuiper, H. v. Meijl, A. Tabeau, M. Verma, D. Oudendag, W.-J. v. Zeist and P. Havlik. (2017). Food and Nutrition Security and Sustainability in Long-Term Projections: An Assessment of the FoodSecure Scenarios. Paper prepared as part of Deliverable 7.4 of the FoodSecure project, foodsecure.eu.

Shutes, L., H.eE. Stehfest, M. van Dijk, M. Kuiper, H. van Meijl, A. Tabeau, M. Verma, D. Oudendag, W.-J. van Zeist and P.Havlik, *forthcoming*, Food and Nutrition Security and Sustainability in Long-Term Projections: An Assessment of the FoodSecure Scenarios. FoodSecure working paper, foodsecure.eu

Siggel, E. (2006). "International competitiveness and comparative advantage: a survey and a proposal for measurement." Journal of Industry, Competition and Trade **6**(2): 137-159.

Siudek, T. and A. Zawojska (2014). "Competitiveness in the economic concepts, theories and empirical research." Acta Scientiarum Polonorum. Oeconomia **13**(1).

Spence, A. M. and H. A. Hazard (1998). International Competitiveness. Cambridge, MA, Ballinger Publishing Company.

Steffen, W., K. Richardson, J. Rockström, S. Cornell, I. Fetzer, E. Bennett, R. Biggs and S. Carpenter (2015). "Planetary boundaries: Guiding human development on a changing planet." Science (New York, N.Y.) 348(6240): 1217-1217.

Stevens, C. J., C. Duprè, E. Dorland, C. Gaudnik, D. J. G. Gowing, A. Bleeker, M. Diekmann, D. Alard, R. Bobbink, D. Fowler, E. Corcket, J. O. Mountford, V. Vandvik, P. A. Aarrestad, S. Muller and N. B. Dise (2010). "Nitrogen deposition threatens species richness of grasslands across Europe." Environmental pollution 158(9): 2940-2945.

SUN (2010). "A Road Map for Scaling-Up Nutrition." First edition.

Terres, J.-M., B. Allen, W. Britz, C. Bulgheroni, J. Dwyer and M. L. Paracchini (2012). "WP5 Rural Development - Indicators. Deliverable 5.2 of the project CAPRI-RD (Common Agricultural Policy Regionalised Impact - The Rural Development Dimension)." 1-41.

Thompson, A. A. and A. J. Strickland (2003). Strategic management. Concepts and Cases. New York, McGraw Hill.

Tillin, H. M., J. G. Hiddink, S. Jennings and M. J. Kaiser (2006). "Chronic bottom trawling alters the functional composition of benthic invertebrate communities on a sea-basin scale." Marine Ecology Progress Series 318: 31-45.

Tooze JA, Midthune D., Dodd KW, FreedmanLS, Krebs-Smith SM, Subar AF, Guenther PM, Carroll RJ, Kipnis V. 2006. A New Statistical Method for Estimating the Usual Intake of Episodically Consumed Foods with Application to Their Distribution. Journal of the American Dietetic Association, 106(10):1575-87.

Unfccc (2015). Adoption of the Paris Agreement. United Nations Framework Convention on Climate Change Conference of the Parties, Paris, November 30 to December 11, 2015, United Nations Framework Convention on Climate Change.

van Grinsven, H. J. M., A. Rabl and T. M. de Kok (2010). "Estimation of incidence and social cost of colon cancer due to nitrate in drinking water in the EU: a tentative cost-benefit assessment." Environmental Health 9(1): 58-58.

Van Kernebeek HRJ, Oosting SJ, Feskens EJM, Gerber PJ, De Boer IJM. (2014). "The effect of nutritional quality on comparing environmental impacts of human diets." Journal of Cleaner Production 73: 88-99.

van Vuuren, D. P., M. Kok, P. L. Lucas, A. G. Prins, R. Alkemade, M. van den Berg, L. Bouwman, S. van der Esch, M. Jeuken, T. Kram and E. Stehfest (2015). "Pathways to achieve a set of ambitious global sustainability objectives by 2050: Explorations using the IMAGE integrated assessment model." Technological Forecasting and Social Change 98: 303-323.

Vandevijvere, S., et al., Monitoring and benchmarking population diet quality globally: a step-wise approach. Obesity Reviews, 2013. 14(s1): p. 135-149.

Vanham, D. and G. Bidoglio (2013). "A review on the indicator water footprint for the EU28." Ecological Indicators 26(2013): 61-75.

Vanham, D. and G. Bidoglio (2014). "The water footprint of agricultural products in European river basins." Environmental Research Letters 9(6): 064007-064007.

Vanham, D., E. Fleischhacker and W. Rauch (2009). "Impact of an extreme dry and hot summer on water supply security in an alpine region." Water Science & Technology 59(3): 469-469.

Watson, R. A., G. B. Nowara, K. Hartmann, B. S. Green, S. R. Tracey and C. G. Carter (2015). "Marine foods sourced from farther as their use of global ocean primary production increases." Nature Communications 6: 7365-7365.

Weissteiner, C. J., C. García-Feced and M. L. Paracchini (2016). "A new view on EU agricultural landscapes: Quantifying patchiness to assess farmland heterogeneity." Ecological Indicators 61: 317-327.

WHO (1995). Physical status: the use and interpretation of anthropometry. Report of a WHO Expert Committee.

WHO (2003) Food based dietary guidelines in the EU region. Copenhagen, Denmark, World Health Organization.

WHO (2012) Guideline: Sodium intake for adults and children. Geneva, World Health Organization.

WHO (2015) Guideline: Sugars intake for adults and children. Geneva, World Health Organization.

WHO/FAO Expert Consultation (2003). Diet, nutrition and the prevention of chronic diseases. World Health Organisation Technical Report Series. 916.

Wijnands, J. H. M. and D. Verhoog (2016). Competitiveness of the EU food industry. An ex-post assessment of the performance embedded in international economic theory. The Hague, LEI Wageningen UR.

Wijnands, J. H. M., H. J. Bremmers, K. J. Poppe and B. M. J. van# der#Meulen (2008). "An economic and legal assessment of the EU food industry's competitiveness." Agribusiness **24**(4): 417 - 439.

Willett WC. Implication of Total Energy intake for epidemiologic analyses. In: Willett WD ed. Nutritional Epidemiology 3rd ed. New York: Oxford University Press, 2012: pp 260-86.

WITS (2013). Online Trade Outcomes Indicators; User's Manual. World integrated Trade Solution Wasinghton, World Bank.

Wright, P., M. J. Kroll and J. Parnell (1998). Strategic Management Concepts. London, Prentice Hall.

Zamudio, A. N., L. Bizikova and M. Keller (2014). "Measuring Local Food Systems' Resilience: Lessons learned from Honduras and Nicaragua. International Institute for Sustainable Development. Climate Resilient Value Chains and Food Systems Briefing Note Series."

Ziegler, F., U. Winther, E. S. Hognes, A. Emanuelsson, V. Sund and H. Ellingsen (2013). "The Carbon Footprint of Norwegian Seafood Products on the Global Seafood Market." Journal of Industrial Ecology 17(1): 103-116.

Zurek, M., J. Ingram, A. Zimmermann, M. Garrone, M. Rutten, I. Tetens, A. Leip, P. v. t. Veer, M. Verain, E. Bouwman, S. Marette, C. Chang, C. Latka, S. Hornborg, F. S. Ziegler, J. Vervoort, T. Achterbosch, I. Terluin, P. Havlik and A. Deppermann (2016). "D1.1 A Framework for Assessing and Devising Policy for Sustainable Food and Nutrition Security in EU: The SUSFANS conceptual framework. SUSFANS, GA no. 633692."