Baseline sustainability assessment of the current state of livestock/fish and fruit/vegetables supply chains

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1 Deliverable short summary for use in media

To assess different possible future directions for the EU food system, potential pathways based on a set of innovations need to be identified towards achieving sustainable healthy diets within the EU without negative implications for the rest of the world. Given diet and environment concerns we focus on two cases the 'livestock and fish case' and 'the fruit and vegetable case'. Based on the current production system and stakeholder consultation we identify novel feeding strategies, including use of waste to increase circularity in livestock production, as the innovation pathway for animal-based production. Innovations for 'the fruit and vegetable case' will focus on increasing people's fruit and vegetable intake using stakeholder defined drivers as the starting point. We end this report with an illustration on how the metrics across different policy domains can be used to assess sustainable FNS through a spider diagram, highlighting both its benefits and potential pitfalls.

2 Teaser for social media

Innovation pathways based on an assessment of the current situation and stakeholder consultations are identified in this report. An illustration across two policy domains shows the potential and pitfalls of a spider diagram presentation.

3 Abstract

To assess different possible future directions for the EU food system, potential pathways based on a set of innovations need to be identified. The aim of WP5 is to define different pathways towards more sustainable and healthy diets within the EU, without negative implications in the rest of world. This first report of WP 5 makes the case for the two selected case studies based on the current situation, provides as first set of innovation pathways and explores the use of metrics in a spider diagram to assess sustainable FNS. The innovations focus on two cases, 'livestock and fish case' and 'the fruit and vegetable case'. For both supply chains there are concerns regarding the current European diet (too high consumption of livestock and too limited consumption fruit, vegetables and seafood), whereas for livestock and fish production there are also pressing environmental concerns (land use, GHG emissions, fish stock depletion).

Innovation pathways can focus either on production or consumption side interventions. Following the project plan the 'livestock and fish case' focuses mainly on production while the 'fruit and vegetable case' focuses on consumption innovations. Based on the current environmental concerns with both livestock and fish production, novel feeding strategies are selected as the main production side innovation for this case. This corresponds to the preference expressed by the stakeholders, who in addition also highlighted the scope for increasing circularity in livestock production. Given concerns around the current diet pattern, however, some consumption side interventions will also be explored when further developing the innovation pathways for livestock/fish. Related to 'the fruit and vegetable case' innovations will focus on how to change people's behaviour to increase fruit and vegetable intake. Here the stakeholders identified a set of potential drivers accounting for both feasibility and importance.

We end this report with an illustration on how the metrics can be used to assess sustainable FNS through the use of a spider diagram. Using illustrative data this 'proof of principle' shows such an assessment can be done for metrics in different policy domains. Working through a numerical example, albeit illustrative, yields important insights on the benefits of having multiple goals in a single figure while also signalling the potential pitfalls of losing details in the aggregation of data needed for such a consolidated representation.

4 Introduction

Historically the main goal of the EU common agricultural policy was to feed the EU population. To accomplish this aim incentives to increase production were provided by a set of policies such as direct production support, border protection, and export support. The EU food system was successful in delivering affordable and sufficient food since then. Similar to land-based agricultural production an increase in EU aquaculture production is also promoted; however, this production has failed to keep up with the global pace of growth. In contrast to agriculture and aquaculture, the EU common fisheries policy aims to decrease current overcapacity and promote sustainable use of limited natural resources. Limiting European fisheries while aquaculture does not keep pace with demand has resulted in the EU depending on seafood imports to meet increased seafood consumption per capita, of varying degree for different products.

Besides the provision of food stimulating productivity of agricultural and fisheries systems also generates economic benefits, resulting in improved livelihoods and employment, but it also has drawbacks. Food production causes severe environmental pressure via emissions to air, water, and soil and we see rising trends in obesity, diabetes and other non-communicable diseases related to the current pattern of food consumption.

Looking beyond the EU we see an increasing amount of food needed to feed the world due to population growth, demographic changes, increased urbanization, and overall changes in dietary patterns (FAO, 2009; Tilman et al., 2011). The world population is expected to grow to about 9.7 billion people in 2050 (United Nations, 2015), while growing incomes and urbanization are expected to increase the intake of processed and animal-source food (ASF) and seafood (FAO, 2016). The global demand for food, especially ASF, therefore, is expected to increase considerably (FAO, 2011).

The EU needs to balance potentially conflicting goals linked to farmer incomes, health concerns and environmental impacts set in a global context of an increasing demand for especially animal-sourced food. These ambitions need to be achieved through a wide array of EU and member state policies, concerned with issues ranging from food production practices, health outcomes, environmental impacts and business considerations. To guide an assessment of developments in the food system, due to (global) autonomous developments as well as targeted interventions, the SUSFANS conceptual framework identifies four overarching policy objectives (described in D1.1 and adjusted in D1.3):

1. Balanced and sufficient diet for EU citizens
2. Reduction of environmental impacts
3. Competitiveness of EU agri-food business
4. Equitable outcomes and conditions

To reach these goals we need to assess in which direction the EU food system can move, while accounting for the trends that we see emerging across the whole (global) food system. Within the SUSFANS project WP5 focuses on identifying innovation pathways towards the objective of achieving sustainable healthy diets within the EU, without negative implications for the rest of the world. To assess progress towards the policy goals along these innovation pathways the framework and metrics developed in WP1 will be applied using the toolbox developed in WP9. By doing so a package of innovation can be identified that provides a pathway towards healthy and sustainable diets.

This report, the first deliverable of WP5, starts by assessing the current (baseline) situation of the EU policy objectives mostly focussing on the two areas (diets and environment) with the most pressing policy concerns linked to the WP 5 case study supply chains of livestock/seafood and fruit & vegetables. This part draws pulls together data collected in WP2 (Food consumption and diets), WP3 (Food supply chains) WP4 (primary agricultural and fisheries production) and during the stakeholder consultations (WP6).

The second part of this deliverable provides a first description of potential innovation pathways to enhance the sustainability and healthiness of European diets drawing on a variety of sources. These innovation pathways will be developed in more detail in D5.2 for livestock/fish and in D5.3 for fruit & vegetables.

The complete assessment of the innovation pathways will be done in D5.4, using the toolbox developed in WP9 to quantify the metrics developed in WP1. To test whether the approach currently developed in WP1 the last part of this deliverable provides an illustrative experiment of assessing metrics from two policy areas (diets and environment), completing the CAPRI-based proof of principle in D4.7. This experiment not only provides feedback to WP1 when finalizing the assessment framework, it also highlights concerns to be taken along when developing the case-studies of WP5 further.

5 Current situation related to the EU diet and environmental policy goals

Starting point for assessing the EU food system is determine the current or baseline situation in terms of the policy goals as defined in WP1. Describing the current situation is needed not only to have a starting point for the forward looking exercises in WP10, but also to determine the need for interventions to steer the EU food system towards the policy goals. In this section we describe for the diet and environmental policy goal the current situation related to livestock/fisheries and fruit/vegetables, based on new information collected in WP1 (Conceptual framework and metrics), WP2 (Food consumption and diets), WP3 (Food supply chains) and WP4 (primary agricultural and fisheries production).

Both the environment and diet goals are clearly present in the policy debate. There are persistent concerns on the (global) environment impact of EU agricultural production, at first because of the historical production focus in the EU agricultural policy but increasingly in the context of the global climate change. For example, reaching the ambitions expressed in the Paris climate agreement will require adjustments in agriculture and specifically livestock production. Providing affordable food for European consumers has been a great success of the CAP, but may also backfire with a growing obesity crisis and concerns on the composition of EU diets. This again has to be set in context of a global shift in diets towards increasing amounts ASF, with the associated environmental implications.

The third goal, competitiveness of EU agri-food business, is less pressing. The EU is a globally leading net exporter of food (EC 2016), indicating its internationally competitiveness. Although EU agriculture as a whole belongs at the global top there are of course differences across sectors and regions with specific products and/or regions warranting closer policy attention. Given the proven overall competitiveness of EU agriculture we do not explicitly account for these in the set-up of the case studies and the discussion below, but this objective will be key in evaluating innovations during the course of SUSFANS. First of all, innovations need to be economically attractive for producers else they will not be adopted. At a more aggregate level the competitiveness goal is key to assure that proposed interventions, being it product innovations or regulations, do not reduce the competitiveness of EU agri-food production.

The fourth goal, equitable outcomes and conditions, relates to equitable outcomes within European supply chains, as well as with regard to Europe's impact on producers and consumers in the rest of the world. It does not feature in the EU food system debates as prominent as the environmental or diet concerns. In the context of SUSFANS it has been added as an explicit and separate policy objective after stakeholder feedback on preliminary versions of D1.3 describing the operationalization of the conceptual frameworks in metrics measuring the policy objectives.

Equity in the outcomes and conditions of the EU food system is not the objective of a single policy but rather represents a clustering of numerous policy aims around the social sustainability of the food system. The EU does not structurally monitor the performance on equity in the EU food system (see also D1.1). Given the recent addition of the goal and issues around operationalizing progress in this area (see D1.3 and D1.4 for more elaborate discussions) it has not been included as an explicit focus of the case study development in WP5. Building on the progress made in WP1 on quantifying the equity goal the innovation pathways will be assessed in this dimension.

This being said we can briefly indicate some implications of the EU food system for global food security linked to livestock and fisheries, which is one of the elements addressed as part of the equity goal. The EU food system is highly dynamic (also described in D4.1). Within the EU food system a large number of agri-food businesses of all sizes works across all different geographical scales, from local to regional to global. Globalization over the last 300 years increased the complexity of supply chains of food production. Nowadays, different stages along the food chain are disconnected and occur in different areas in the world.

We observe an increasing separation between the location of production and consumption of e.g. animal-source food. Similarly, production of livestock feed is no longer necessarily connected to keeping of animals. Pork production in the Netherlands, for example, uses feed ingredients cultivated all over the world e.g. soybean meal is mainly cultivated in Brazil whereas wheat is mainly cultivated in Germany. Seafood from aquaculture is mainly produced in Asia (FAO 2016). Production and consumption of animal-source food, therefore, no longer has only local impacts. The consumption of Pangasius in Europe, for example, can affect the livelihoods of smallholders in East and South-East Asia, whereas the production of pork in the Netherlands can result in deforestation in South-East

America. Global fisheries resources are highly skewed towards utilization by a limited number of mainly developed countries (Swartz et al. 2010); the full effect on food security for countries with undernourished citizens is currently debated (Smith et al. 2010; Golden et al. 2016; Black et al. 2013). It, therefore, should be kept in mind that direct EU development policy actions to affect food and nutrition security in developing countries, might have indirect impacts on global food and nutrition security.

The remainder of this section will zoom in on the current or baseline situation for livestock/fish and fruit/vegetables in relation to the first two policy objectives on EU diets and environmental impacts.

5.1 Balanced and sufficient diets for EU citizens

In D1.1 healthy diets are defined as balanced diets that provide adequate amounts of energy and nutrients for a healthy life and well-being for the whole population.

5.1.1 Trends in European diets

Assessing the healthiness of diets is not straightforward, and a wide variety of detailed variables are used to assess balance and healthiness of EU diets (see D1.3 and D1.4 for more details on the operationalization of this metric). A first straightforward reference point for diet developments are the European recommendations for daily intake of energy and protein (Table 1). We will use these below to asses trends in EU diets, in general and for (animal) protein in particular.

*Table **1** - Dietary Reference Values for energy and protein for the European population*

	Energy		**Protein**	
	Average Requirement (AR)		Population Reference Intake (PRI)	
	MJ/d	*Kcal/d*	*g/kg BW/d*	*g/d*
Women	8.6	2055	0.83	52
Men	10.7	2556	0.83	62

Source: EFSA (2012); EFSA (2013)

Over the past decades the intake of animal-source food (ASF) in Europe has increased while at the same time the consumption of vegetables and fruit has decreased. The current dietary consumption pattern in Europe is characterized by a higher than required intake of energy. Where the average recommended energy intake is 2306 Kcal/d, the FAO estimates an average EU intake of 3409 Kcal/day (Figure 1). A note of caution with the FAO numbers needs to be made, however. Their calculations are based on available food for consumption, being computed from the production side and not from household purchases or individual intake data. Their estimates are therefore likely to overestimate the actual consumption, for example because of food waste by consumers. The actual excess energy intake compared to the recommended quantities can therefore be expected to be lower than suggested by comparison to the FAO numbers.

Food consumption is also assessed in a number of European countries from national dietary surveys. EFSA has compiled such data from European countries in a harmonized way (https://www.efsa.europa.eu/de/node/949501). Average energy intake among the adult population in the four selected European case study countries for SUSFANS (Czech Republic, Denmark, France and Italy) are shown in of Table 2.

Table 2: Dietary intake of energy and protein in adults aged 19-65 years in SUSFANS case study countries

		Energy intake			**Protein intake**			
		MJ/d (Kcal/d)		Kcal/d	g/d			E%
	N	Mean	SD	Mean	Mean	SD	Mean	SD
Women								
Czech Republic	*1094*	9.7	3	2317	n.r.		14.7	7.7
Denmark	*1785*	7.9	2.1	1887	67	18	15	2.4
France	*1499*	7.2	0.1	1720	n.r.		17	0.1
Italy	*1245*	8.1	2.2	1935	76	20	15.9	2.3
Men								
Czech Republic	*1046*	12.4	3.7	2962	103*		14.1	4
Denmark	*1569*	10.4	2.9	2485	87	25	14	2.3
France	*852*	10	0.1	2389	96*		16.3	0.1
Italy	*1068*	10	2.7	2389	92.6	25	15.7	2.2

n.r. = not reported; *=not reported but calculated

Source: EFSA (2012); EFSA (2013)

These average intakes are considerably below the FAO estimate of 3409 Kcal/day in line with the expected overestimation of the FAO consumption numbers. Table 2 also shows quite a divergence across the four countries. Average reported intake of energy (mean values) ranges from 1720 (France) to 2317 (Czech Republic) per day in women while for men we see a range from

2389 (France and Italy) to 2962 Kcal/day (Czech Republic). In addition to the divergence across countries the standard deviations also point to divergence within countries. For these four countries only Czech Republic exceeds the European recommendation for both women (2055 Kcal/day) and men (2556 Kcal/day). These numbers, however, only present averages obscuring large variations within countries both in consumption patterns and in dietary needs. The Czech Republic standing out in terms of excess calorie consumption is not unexpected with this country also having the lowest income per capita; excess calorie consumption and unbalanced diets are strongly correlated to socio-economic classes often captured by education levels in nutrition studies.

The general consensus for the EU is that compared to the recommended quantities there is an excess consumption of energy (calories), protein (including animal protein), saturated fat, and added sugar. Combined with too low an intake of fruit and vegetables this consumption pattern of insufficient intake of dietary fibre, certain micronutrients (e.g. vitamin D, folate; iodine and iron in certain sub-groups of the population), together with the nutrients in excess is directly correlated with chronic non-communicable diseases (NCDs), such as overweight, obesity, heart diseases, metabolic syndrome, cancer, and osteoporosis (Gerbens-Leenes et al., 2010; Micha et al., 2010; Kastner et al., 2012; Hallström, 2015). As stated in D1.1 'NCD's make the largest contribution to the burden of disease in the European countries (WHO - Regional Committee for Europe 2014). NCDs are not just a European concern, they contribute to around 68% of global deaths (38 million) in 2012 up from playing a role in 60% of deaths in 2000. Worryingly from an equity point of view is that NCDs affect a disproportionate number of people from poorer or lower income countries (Anon n.d.)'.

5.1.2 **European protein consumption**

Figure 1 presents the FAO estimates of protein consumption in the EU by source, both in calories and in gram per capita per day. Again the same caveats regarding the supply side calculations of the FAO numbers and the large variation across and within countries highlighted above apply. These food balance sheet based estimates that for Europe, the consumption of total protein is about 104 g per person per day (FAO, 2016) which is well above the average European recommendation of 57 g per day (Table 1). Of this total protein 58 percent comes from animal sources. Looking at total energy consumption according to the FAO 29 percent is supplied by animal products (FAO, 2016).

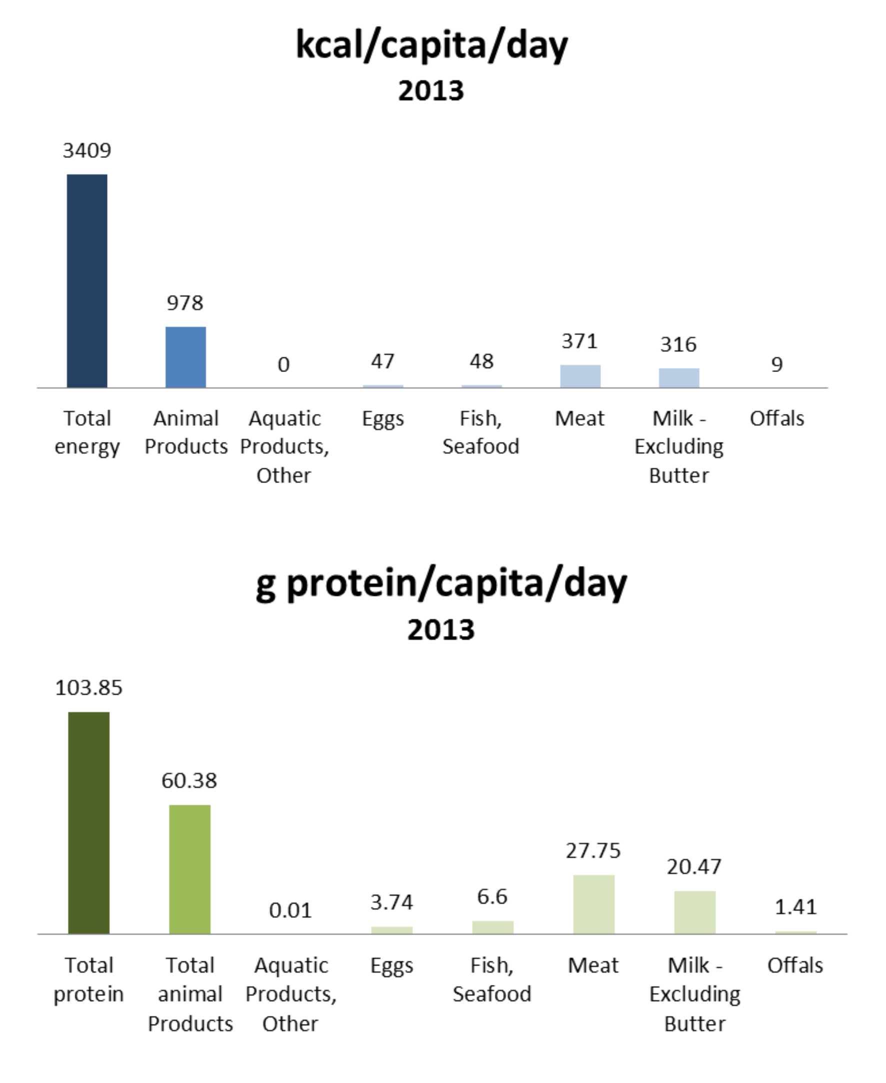


Figure 1: Kcal and protein supply per person per day in 2013 in the EU (FAOSTAT)

Again the EFSA data for the case study countries based on actual intake surveys are much lower than the FAO estimates (Table 2). In contrast to the energy intake, however, average protein intake in all countries exceeds the recommendations for both men (62 g) and women (52 g); ranging from 67-76 g per day for women and from 87-93 g per day for men. The recommendations are based on a Population Reference Intake (PRI) for proteins of 0.83 g protein per kg body weight per day and applicable both to high quality protein and to protein in mixed diets (EFSA, 2012).

Seafood is generally a healthy alternative in a diet, even if some species from certain fishing areas may cause health risks due to contaminants. Besides providing protein, seafood however also serves as an important source of minerals (including calcium, iodine, zinc, iron and selenium), contains all essential amino acids, and provides essential fats (e.g. long-chain omega-3 fatty acids) and vitamins (D, A and B). Dietary advices in developed countries accordingly often recommend eating more seafood and vegetables and less beef (Thurstan and Roberts 2014). With over 2,500 species being fished for and over 600 species being farmed, the seafood sector is overall truly diverse which could contribute to resilience of the seafood system. However, consumers in the EU and other high income regions prefer to eat seafood species at the top of the food web, which are less abundant in natural ecosystems and require more resources when farmed.

At present, seafood accounts for approximately 17% of the global population's intake of animal protein and 6.5% of all protein consumed (FAO, 2016). According to Figure 1 the average EU consumption of seafood is 11% of animal protein, it thus plays a less important role in the EU's animal protein consumption than it does globally.

Using the intake-based EFSA data for the case study countries we can get a better idea of the source of dietary protein intake in the EU.

Table 3 provides the shares of the main sources of adult dietary protein intake in the four case study countries. In all cases more than half the protein is derived from animal sources, ranging from 53% in Czech Republic to 65% in France. There appears quite some variety in the role of fish and seafood in the diets, only contributing 6% of animal protein intake in Czech Republic while Italy comes in at 16% equal to the global average contribution of fish to animal protein consumption.

Table 3: Main food contributors to dietary protein intake of adults (18-64 years) in selected European countries (%)

	Animal sourced			Fruit and vegetable sourced			Shares by type	
	Meat & meat products	*Milk & milk products*	*Fish & seafood products*	*Grains & grain-based products*	*Vegetable & vegetable products*	*Fruit & fruit products*	*Animal sourced protein in total protein*	*Fish and seafood in animal protein*
Czech Republic	35	15	3	28	4	1	53	6
Denmark	32	25	4	23	2	1	61	7
France	39	19	7	20	2	1	65	11
Italy	28	20	9	28	4	1	57	16

Source: EFSA (2013)

5.1.3 European fruit and vegetable consumption

Comparing the current energy and protein intake to the recommendations given by EFSA it can be concluded that energy and protein intake in the European diets is affluent. On the other hand, the EFSA and FAO data also show that the fruit and vegetable intake in Europe differs considerably between countries and remains below the level recommended (400 grams of fruits and vegetables per day) by the World Health Organisation, while other national bodies recommend 500 g of fruit and vegetables per day (France), or 600 g/d (Denmark)(http://www.fao.org/nutrition/nutrition-education/food-dietary-guidelines/en/).

Table 4 explores in more detail the dietary patterns in the four case study countries based on the EFSA food intake data. Fruit and vegetable consumption is limited to 250g per day in Czech Republic, 282g in France and 366g in Denmark. According to these data only Italy with a consumption of 425g per day meets the WHO recommendation, while still being below the recommendations used in France and Denmark. There is thus a wide variety in consumption patterns across the four countries showing the limitation of drawing conclusions from average consumption levels.

Table 4: Food consumption in the adult population in selected European countries (g/pers/d)

	Czech Republic	Denmark	France	Italy
Survey year	*2003*	*2005-08*	*2007*	*2005-06*
Adults in survey, n	*1.666*	*1.739,0*	*2276*	*2313*
Grains & cereals products	278	209	226	251
Meat and meat products	185	132	134	113
Fish and other seafood	17	21	30	46
Milk and dairy products	172	364	201	186
Eggs and egg products	20	17	15	21
Veg & veg products	126	170	145	235
Starchy roots and tubers	97	93	67	49
Legumes, nuts & oilseeds	9	11	36	13
Fruit and fruit products	124	196	137	190
Fruit and vegetable juices	32	80	56	30
Sugar and confectionary	26	34	24	20
Snacks, desserts, & other	14	12	25	12
Animal and veg fats& oils	41	30	27	40
Non-alcoholic bevs (excl. milk)	109	959	462	165
Alcoholic beverages	432	263	118	107
Drinking water	1313	1065	816	672

Veg= vegetables

Source: EFSA Comprehensive European Food Consumption Database

https://www.efsa.europa.eu/de/node/949501

Assessed on July 10, 2016

Apart from the in most cases limited fruit and vegetable consumption Table 4 shows clearly that food consumption patterns are very country-specific. For example Czech Republic has a relatively high meat and alcohol consumption, Denmark has the highest milk and non-alcoholic beverage consumption, while Italy stands out in terms of vegetable consumption. The Danish consume more fruits, the meeting of the WHO recommendation by Italy is thus to a large extent due to a its vegetable consumption.

5.2 Reduced environmental impacts of the EU food system

To reduce the environmental impact the EU made some agreements resulting in a set of targets e.g. Kyoto Protocol. To reduce GHG emission, for example, reductions are regulated by the 2020 climate & energy package within the EU legislation that sets three key targets: 20% cut in greenhouse gas emissions (from 1990 levels), 20% of EU energy from renewables, 20% improvement in energy efficiency. Looking at the environmental impact of diets it is worthwhile to take a closer look at livestock and seafood where the concerns are most pressing.

5.2.1 Livestock

Besides certain diet-related health issues, consumption of high amounts of ASF also causes severe environmental pressure via emissions to air, water, and soil (Steinfeld et al., 2006). It has been estimated that food consumed in Europe is responsible for about one third of the total European anthropogenic greenhouse gas emissions. Worldwide food consumption causes 25% of the global anthropogenic greenhouse gas emissions (Tilman and Clark, 2014) and the majority (around 60%) originates from livestock production (Gerber et al., 2013).

Besides climate change, the livestock sector also has a large impact on eutrophication and acidification (Leip et al., 2015) and competes increasingly for scarce resources, such as land, water, phosphorus sources, and fossil-energy (Steinfeld et al., 2006; De Vries and De Boer, 2010; Leip et al., 2015). Global livestock production occupies about 30% of the permanent ice-free land on our planet, when all cropland and grassland used for feed are included (Steinfeld et al., 2006). In 2012, about 5 billion hectare of land was used for agriculture (FAO, 2015), of which about 70% was used for livestock production (Steinfeld et al., 2006). The livestock sector is the world's largest user of agricultural land, through grazing and the use of feed crops. Of the 5 billion hectares of agricultural land, about 1.6 billion hectares is arable land, of which 33% is dedicated to feed-crops (Steinfeld et al., 2006). Currently about 80% of new croplands replace forests (Foley et al., 2007; Gibbs et al., 2010; Foley et al., 2011).

5.2.2 Seafood

Seafood from capture fisheries is a large-scale food production system based on a wild resource. It is sometimes argued that fisheries is 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).

Over-exploitation is manifested in the form of depletion of predatory fish, 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); the full effects of fisheries on marine ecosystems are still unknown. Fuel use is also highly variable between fisheries, with the global median of 639 L/tonne landed, but may range between 8 L to over 17 000 L/tonne (Parker and Tyedmers 2015).

Seafood production from aquaculture is exhibiting an increase in production volume since the 1980s (FAO 2016). 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. For salmonid production in open net pens, feed accounts for, on average, nearly 90% of total GHG emission and energy use (Tyedmers et al. 2007).

6 Innovation pathways

From the description of the European diets we can conclude that compared to the European recommendations EU citizens on average consume too much energy and livestock products, while consumption of seafood and fruit & vegetables could be increased. At the same time current production systems of livestock and seafood have negative environmental impacts which are a cause of concern. Although not yet thoroughly assessed with the metrics under development in WP1, these preliminary assessments provide the rationale for developing in WP5 transformation pathways to more health and sustainable European diets focussing on livestock/fish and vegetables/fruit. In the course of SUSFANS these pathways will be assessed using the SUSFANS toolbox developed in WP9 against the metrics developed in WP1.

6.1 Production- and consumption-side interventions

As outlined in the SUSFANS conceptual framework (D1.1) producers and consumers are key actors in the food system. Mitigation strategies or innovations for feeding the European population sustainably can also be divided in a production-side perspective or a consumption side perspective. Production-side strategies are innovations that result in a healthy sustainable diet by changing the production of food items and consumption-side strategies are innovations that focus on changing the human consumption patterns (Gerbens-Leenes and Nonhebel, 2002; Godfray et al., 2010; Foley et al., 2011; Garnett, 2011).

In WP5 two case studies are developed for exploring the scope for moving towards more health and sustainable European diets. The case study of livestock and seafood focuses on both consumption-side[1]and production-side strategies, since the baseline assessment of the current diets raises concerns on the health implications of the current consumption pattern, while current livestock and seafood production systems have environmental concerns as well. The fruit and vegetables case focus mainly on consumption-side strategies, with current average consumption being well below recommended quantities. Both cases will be assessed in terms of the full set of metrics developed in WP1, i.e. covering diets, environment, competitiveness and equity impacts, using the tools from WP9.

[1] In the description of WP5 only production-side strategies are include we, however, aim to also include consumption-side strategies.

To give an example of possible innovations that can be implemented on the production-side and the consumption-side and how they can contribute to a more healthy and planet-friendly diet, we developed Figure 2. Here you can see that as a starting point we first moved from the current situation towards healthy diets according to the EFSA guidelines (orange dot). This strategy requires a change in behaviour and is, therefore, mainly a consumption-side strategy. Key changes required include a reduction of energy intake, a reduction of red meat intake, and an increase in fruit and vegetable intake.

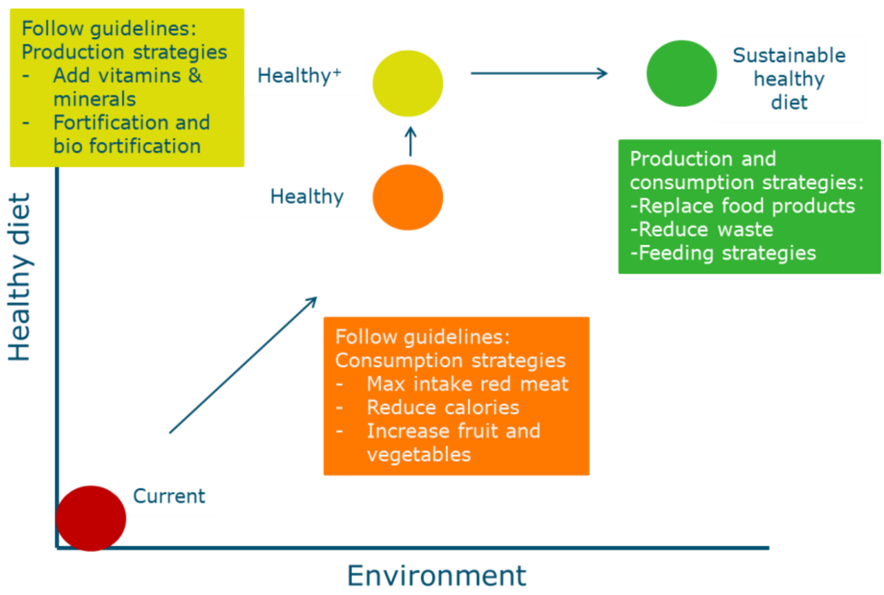


Figure 2: Example of how innovations can help to reach heathy and planet-friendly diet

Due to high impact intensities of red meat we might expect a benefit for the environment. Nevertheless, it might also results in an increased environmental impact. Red meat consumption might be reduced, but milk intake might need to be increased to meet dietary recommendation (something we see in the UK). Whether or not following the dietary recommendation will result in a reduced environmental impact is therefore something that needs to be assessed and cannot be assumed a-priori.

The orange dot in Figure 2, furthermore, might also not provide an optimal health situation. There are certain health issues that cannot be solved by changing consumption patterns. Certain health issues such as a deficiency of vitamin D also relates to behaviour (lack of outside activities). Deficiency of vitamin D might be solved by supplements or by fortification or bio-fortification. Such strategies, however, require new development within the production-side and are, therefore, mainly production-side strategies (light green dot).

To come from a healthy diet (light green dot) towards a more sustainable diets (dark green dot) certain consumption- and production-side strategies might be implemented. Consumption-side strategies might be replacing chicken proteins with insect proteins and production-side strategies might be reducing waste along the production line or feeding strategies such as feeding food-waste to livestock.

By implementing such innovation or a packages of the above mentioned innovations, consumers can move towards a healthy and sustainable diet and is, therefore, called an innovation pathway. The innovation pathway described above mainly focusses on the first two policy goals (diets and environment). One should, however, make sure that implementing package(s) of innovations towards a healthy and sustainable diet does not result in trade-off with the other policy goals (competiveness and equity) and preferably results in synergies. The innovation pathways will thus be assessed in all four policy domains defined in WP1. In the remainder of this section possible innovations in the two case studies – livestock & seafood and fruit & vegetables –will be described in more detail.

6.2 Livestock and seafood case

6.2.1 Production-side strategies

Production-side strategies focus on increasing or maintaining the production volume to meet demand for ASF while increasing efficiency (decrease environmental impact per kg of ASF) and focus on technical innovations and managerial improvements.

Livestock. Looking at the production chain of ASF, differences in environmental impact between pork, chicken, and beef can be seen. Those differences can be explained in part by differences in feed efficiency, reproduction rate, and enteric CH_4 emission (Garnett, 2009; De Vries and De Boer, 2010). Feed production and utilization of feed has the largest impact on greenhouse gas (GHG) emissions and land use (LU) (De Vries and De Boer, 2010; Gerber et al., 2013). About half (47%) of all GHG emissions produced globally by the livestock sector are related to feed production (Gerber et al., 2013). In Europe, the contribution of feed production to emissions from ASF relevant for air and soil quality has been estimated at ca 53% and the contribution of feed production to Global Warming at 66% (Leip et al., 2015). Impact of ASF to water quality is virtually all caused by feed production, including grazing. More details about the environmental impact of livestock production are provided in D4.1.

Seafood. Together with farmed salmon, the most consumed seafood in the EU is wild-caught tuna and cod. Fisheries vary considerably in terms of environmental pressures depending on e.g. gears used, exploitation level and fleet structure. In terms of GHG emissions, fuel use on fishing vessels generally dominates contribution from wild-caught seafood (Ziegler et al. 2016a). Improvement potential from the production side for wild-caught seafood mainly call for innovation pathways on the fisheries management side. This could be done through promoting best available fishing technology (gear use and fleet characteristics), while respecting the limits of natural production and allow for keeping a fishing pressure that is optimized in terms of catch efficiency (high catch per unit effort) without compromising long-term yield.

For farmed seafood, feed demand is dominating in terms of contribution to GHG emissions (Ziegler et al. 2016a) and feed innovation that allows for minimized competition of resources and reduce dependence on fisheries is imperative for farmed seafood to add to the global food system (Troell et al. 2014; Merino et al. 2012). Thus, the innovation pathway from the production side of seafood that has the highest overall potential for considerable growth in production volume comprises of enabling sustainable growth for aquaculture through use of different waste streams for feed. More details about the environmental impact of seafood production are provided in D4.1.

Innovations and feed production. As feed production has a large impart on the environment for both livestock and farmed seafood, we mainly focus on production-side strategies related to feed production. Examples of novel feeding strategies for livestock are: food-waste, waste-fed insects as livestock feed (Makkar et al., 2014), and producing algae for bio-diesel production and the protein co-product for livestock feed (Craigie, 2011; Boland et al., 2013; Van der Burg et al., 2013). Examples of novel feeding strategies for seafood are: replacing conventional feedstock that are based on fisheries and agriculture with insects, algae or microbes (e.g Martínez-Córdova et al. 2016; Draganovic et al. 2013; Barroso et al. 2014).

Innovations and stakeholders. The focus on novel feeding strategies is in-line with the results of the SUSFANS stakeholder meetings. For livestock production stakeholders addressed the importance of using novel protein sources and feed sources that humans cannot or will not eat. There are several products that humans cannot or will not eat, that are suitable as livestock feed, e.g. co-products, food-waste, and biomass from marginal land. Feeding co-products or food-waste to livestock or seafood, or using biomass from marginal lands to feed livestock, further referred to as 'leftover streams', are effective options of using resources. By feeding leftovers, an inedible stream for humans can be transformed into high-quality food products, such as meat, milk, and seafood (Nonhebel, 2004; Elferink et al., 2008; Garnett, 2009; Wirsenius et al., 2010). Besides novel feed sources stakeholders were interested in more circular production systems. This could be achieved by increased integration of livestock and crop production, resulting in food production systems that aim to maximize the number of people to be nourished per ha instead of solely increasing efficiency of the animal itself. Feeding leftover streams to livestock is one way of contributing to more circular production systems.

For seafood production there was a request from stakeholders to assess the potential of fishing at equilibrium, i.e. optimize long-term yield through fishing at maximum sustainable yield (MSY). Another innovation pathway thus focuses on best available management and technology for fishing. Fishing at maximum sustainable yield could be considered as a policy goal; it is an objective of the EU common fisheries policy. However, it is questionable if the models can include enough detail to capture this metric, as the input values varies between years and stocks of the target species. Even when fishing at MSY, there will be different environmental impacts depending on gear use and fleet characteristics (Ziegler et al. 2016b; Parker & Tyedmers 2015). Mitigation strategies related to the production side of seafood can focus on 1) changed feed sources (algae, waste, insects) for livestock and Atlantic salmon (most consumed farmed species in EU today), 2) towards more circular production systems; and 3) optimized fishing for tuna and cod (most consumed wild-caught seafood in EU today).

6.2.2 Consumption-side strategies

As stated above the production of ASF has a high environmental impact and, furthermore, a high intake of ASF can result in human health issues. Eating less or no ASF is an often suggested solution to reduce the environmental impact of the human diet (Gerbens-Leenes and Nonhebel, 2002; Godfray et al., 2010; Foley et al., 2011; Garnett, 2011; Meier and Christen, 2012; Scarborough et al., 2014; Hallström et al., 2015). Furthermore, shifting the type of ASF e.g. from ruminant meat to monogastric meat or seafood or plants, is also often offered as a strategy to reduce the environmental impact of human diets (Wirsenius et al., 2010; Nijdam et al., 2012; Hallström et al., 2015). Consumption-side strategies, focussing on changes in human diet patterns, therefore, can reduce both environmental problems and health issues (Garnett, 2011; Smith et al., 2014; Schader et al., 2015). Although European diets seem to be affluent in protein, ASF provides besides protein also essential nutrients with a high bio-availability, such as iron, calcium, thiamine, vitamin B12, and Zn, simply eliminating ASF in European diets might, therefore, result in health problems (see D2.2 for more details). Replacement of ASF by alternative sources, therefore, should also consider other nutritional aspects of ASF.

Mitigation strategies related changes in human diet patterns can focus on four different replacement strategies: 1) replacing beef-based-protein with pork/chicken-based-protein 2) replacing animal-based-proteins with plant-based-proteins, 3) replacing animal-based-protein with seafood-based-proteins, or 4) replacing animal-based-proteins with insects-based-proteins.

1) Replacing beef-based-protein with pork/chicken-based-protein. De Vries and De Boer (2010) showed that there is a large variation in the environmental impact among livestock products. Compared to beef production, production of pork and chicken results in lower emissions of greenhouse gases, and requires less land and energy along the production chain than beef production. From an environmental perspective it is, therefore, often suggested to replace beef with pork or chicken.

2) Replacing terrestrial animal-based-proteins with plant-based-proteins (bean burger). No matter how efficiently cereals, pulses, and oilseeds are produced, direct consumption of these products by humans is ecologically always more efficient than consumption of ASF produced by animals fed these products

(Godfray et al., 2010; Foley et al., 2011). A mitigation strategy, therefore, is to replace terrestrial ASF with plant-based food.

3) Replacing terrestrial animal-based-protein with seafood-based-proteins. Consumers in many countries are advised to eat seafood two to three times per week, related to assumed health benefits of a safe seafood-rich diet. European consumers tend to choose mainly wild-caught seafood (such as tuna and cod) and a low variety of farmed fish (mainly salmon). From a positive side, these systems are generally in the lower range in terms of energy use and greenhouse gas emissions compared to land-based animal production systems; eating less red meat and more popular seafood (farmed salmon, cod and tuna) thus have the potential to contribute to improved FNS. However, globally, there are only few fish stocks that could tolerate increased fishing pressure, and thus there is little room to expand fisheries.

Aquaculture is the fastest-growing animal production sector in the world and bridges the gap between limited supply from fisheries and increasing seafood demand from consumers. Aquaculture, however, is not independent from fisheries, since many forms of aquaculture rely on the input of marine feeds. Whether or not replacing conventional ASF with seafood results in an improved environmental impact thus needs to be explored. Impacts are highly dependent on which ASF product is replaced with which seafood product. Beside focussing on the most commonly consumed seafood we can, therefore, also explore a change in seafood consumption habits. Increased direct consumption of low-impact seafood otherwise destined for feed, such as herring and by-products, is one innovation pathway. Another one is replacing traditional salmon production with more low-impact seafood types like mussels and carps.

4) Replacing terrestrial animal-based-proteins with insects-based-proteins. Although insects are not seen as a common food source in Europe, edible insects contain high quality protein, vitamins, and amino acids for humans. Furthermore, insects are interesting from an environmental point of view as they have a high food conversion rate, e.g. crickets need six times less feed than cattle, four times less than sheep, and twice less than pigs and broiler chickens to produce the same amount of protein. Insects, therefore, might have potential to replace conventional ASF products.

At the stakeholder meetings most stakeholders were interested in reducing meat consumption and in particular the consumption of processed meat. Furthermore, consumer waste reduction was mentioned as an important strategy and lastly the replacement of meat by other protein sources.

For more details about the stakeholder meetings see the stakeholder meeting reports from WP6. In D5.2 the innovations and potential innovation pathways for the livestock/fish supply chain will be developed in more detail to prepare for the assessment of the innovations in D5.4.

6.3 Fruit and vegetable case

Fruits and vegetables (F&V) are important contributors to a balanced and sufficient diet as important sources of nutrients, including dietary fibre, micronutrients (i.e. vitamin C, folate, potassium) and phytochemicals. From a public health perspective, fruits and vegetables are considered to play a key role in providing a diverse and nutritious diet, and an adequate consumption of fruits and vegetables reduces the risk of certain chronic diseases (WHO 2014, 2003a, 2003b, 2015, 2013). Research has convincingly shown that replacing high energy density foods (high energy per weight of food) with fruits and vegetables (low energy density) can be an important part of a weight-management strategy. A daily intake of minimum 400 g is recommended by many international organizations and national bodies (http://www.fao.org/nutrition/nutrition-education/food-dietary-guidelines/en/).

From an environmental perspective an increased fruit and vegetable consumption together with other plant foods can have environmental benefits if a concurrent reduction in the consumption of animal-based foods takes place (Burlingame 2012; (Garnett 2014; FAO Food Climate Research Network 2016; Ranganathan et al. 2016).

The EU supported ISAFRUIT project provides an important basis for the development of consumer-driven and responsive innovation pathways in relation to fulfilling the needs, demands, and preferences of consumers in relation to fruit. This project identified the trends in Europe associated with fruit consumption, and identified several drivers related to fruit consumption, including availability, convenience, demography, eating habits, health, knowledge, origin, price, and processing. Importantly, this project also showed geographical differences in drivers between countries and between north and south Europe. For the SUSFANS project, the knowledge about drivers for fruit consumption will also be applied to vegetables.

Information from the 1st SUSFANS Stakeholder workshop in October 2015 on Stakeholder's views on possible barriers for consumers for an increase in the consumption of F&V were also taken on board. Key barriers to increase the consumption of fruit and vegetables that identified by the stakeholders are:

- Insufficient perception of the healthiness of F&V;
- Difficulties in promoting consumption of fresh fruit and vegetables as they do not have a 'brand';
- Lack of education on healthy eating habits with more F&V;
- Lack of demand for F&V grown sustainably;
- Lack of willingness to pay for more healthy and/or sustainable F&V – in particular in more vulnerable groups;
- Lack of means to afford some of the F&V products - particular issue in more vulnerable groups;
- Unwillingness to accept and purchase new products;
- Unwillingness to accept new technologies;
- Lack of knowledge on food systems processes in relation to fruit and vegetables and their consequences for health and environment;
- Changes in lifestyle with a current increasing demand for processed and pre-prepared foods;
- Insufficient differentiation between consumer groups and their specific choices;
- Overall lack of a supportive environment for an increased fruit and vegetable consumption.

Consumer-driven supply chains in relation to fruit and vegetables focus on innovation that will fulfil the consumer needs, demands, and preferences. To obtain a successful set of innovation pathways, the food chain sector must understand and respond to the current trends tempting the consumers to increase their intake of fruit and vegetable (Zimmermann and Lans 2009).

Information from the 2nd SUSFANS Stakeholder workshop in October 2016 revealed a number of innovation pathways in the fruit-vegetable supply chain.

Potential drivers for innovation pathways from the consumer's perspective are:

- Access (i.e. affordability)
- Availability
- Convenience (e.g. cut fruits vs non-cut; processed vs raw; preparation time needed)
- Cultural identity / localness (i.e. terroir)
- Demography (know your target age group)
- Education
- Health claims
- Knowledge
- Marketing on health claims
- New technologies and channels (e.g. online shopping, recipes, apps, farmers markets)
- Origin of production
- Packaging
- Price
- Processing types/methods
- Product information (e.g. label)
- Product innovation (e.g. new tastes, sizes, colours)
- Product variation/diversity (more alternatives)
- Production mode (e.g. organic vs conventional; use of GMOs vs conventional)
- Public procurement (linked to availability)
- Quality (OBS! Normative).Needs this to be defined case by case)
- Safety
- Seasonality
- Storage
- Sustainability (e.g. climate compensation)
- Taste
- Waste, incl. loss
- Welfare (e.g. social conditions of workers)

During the course of the 2nd SUSFANS Stakeholder workshop discussions on the feasibility and importance of the various drivers for innovation pathways using a consumer-driven approach were ranked with respect to their feasibility and importance as shown in

Table 5.

Table 5: Drivers of innovation pathways for meeting the consumer needs, demands and preferences ranked according to feasibility and importance

Rank	Feasibility	Importance:
1	**Convenience**	**Price**
2	**New tech and channels**	**Convenience**
3	**Price**	**Education**
4	**Education**	**Taste**
5	**Taste**	**Public procurement**
6	Public procurement	Product innovation
7	Origin	
8	Waste	
9	Marketing on health claims	
10	GMO	
11	Product variation	
12	Processing	

Potential innovation pathways from a consumer-driven approach were discussed and the general discussion included the following points:

- Environment – depends on where the F&V are produced, how, what crops/commodities, where they are consumed
- F&V clearly good for a balanced diet – but not necessarily good for the environment (depending on what, where and how – production practices)
- Place of production versus place of consumption also has consequences for global food security
- Production is a key leverage point
- Criteria and assumptions about crop production important for the determination on whether sustainable or not.
- At this step it would perhaps be relevant to separate the discussion for F&V, respectively (vegetables more universal production potential).
- Take on international trade: good or bad? Diversity vs sustainability? The bulk of environmental impacts occurs at the agricultural stage so consider the environmental impacts downstream as 'tolerable' if mitigated at the agricultural stage?
  - E.g. bananas only for tropical countries to consume? (Inadequate for production in temperate countries)
  - Local isn't always better/ more sustainable.
  - Seasonal usually more accurate.
  - Depriving exporting countries from their revenue?
  - Simplification of the GFS if it is increasingly globalised? (Less local varieties?)

- Additives/preservatives: food safety and less waste vs health issue
- Discussion should not be about local versus global – rather about sustainable production, processing, transport etc.

7 SUSFANS toolbox: proof of principle

The contribution of each innovation to the four policy goals will be quantified with the SUSFANS toolbox using the metrics developed in D1.3. D1.4 provides an overview of which model can assess which performance metrics (see appendix), showing that an individual model such as SHARP or CAPRI is not able to assess all performance metrics. By using a combination of models we are able to cover almost all the different performance metrics.

The next step is to apply and demonstrate the SUSFANS performance metrics, which was done for a single policy goal in D4.7. The assessment of D4.7 was performed with CAPRI for the policy goal "Reduced environmental impacts of the food system". The results, although meant as a trail/experiment, demonstrate that the indicators and metrics are straightforward to implement and easy to interpret. The assessment showed that it possible to identify improvements compared to a reference situation and the defined policy goals or policy targets. This makes it possible to compare the impact of innovations in different domains of performance metrics or aggregate indicators and over Member States or groups of countries.

7.1 Proof of principle across two policy goals

In addition to D4.7 - which can be seen as a 'proof of principle' for a single policy goal - we aim, by performing an experimental assessment, to link the metrics to multiple policy goals using a spider diagram, to illustrate the strength of conceptual framework. In line with the focus of this deliverable so far we focus on two policy goals namely: 'Balanced and sufficient diets for EU citizens' and 'Reduced environmental impacts of the food system'. For the policy goal 'Balanced and sufficient diets for EU citizens' we use two performance metrics: 'food based dietary guidelines', and 'energy balance'. For the policy goal and 'Reduced environmental impacts of the food system' we use 'climate stabilisation'. The illustration assesses the difference between the years 2003 and 2013, the latest year for which a complete set of data needed for this illustration could be compiled.

The performance metrics 'food based dietary guidelines' was computed on the diet balance indicator that contains scores for the five key foods: vegetable intake, fruit intake, fish intake, meat intake. The score is based on the formulas in the box below. These formulas result in the calculation set-up summarized in Table 6.

Formula for computing a score on the 'food based dietary guidelines' metric
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

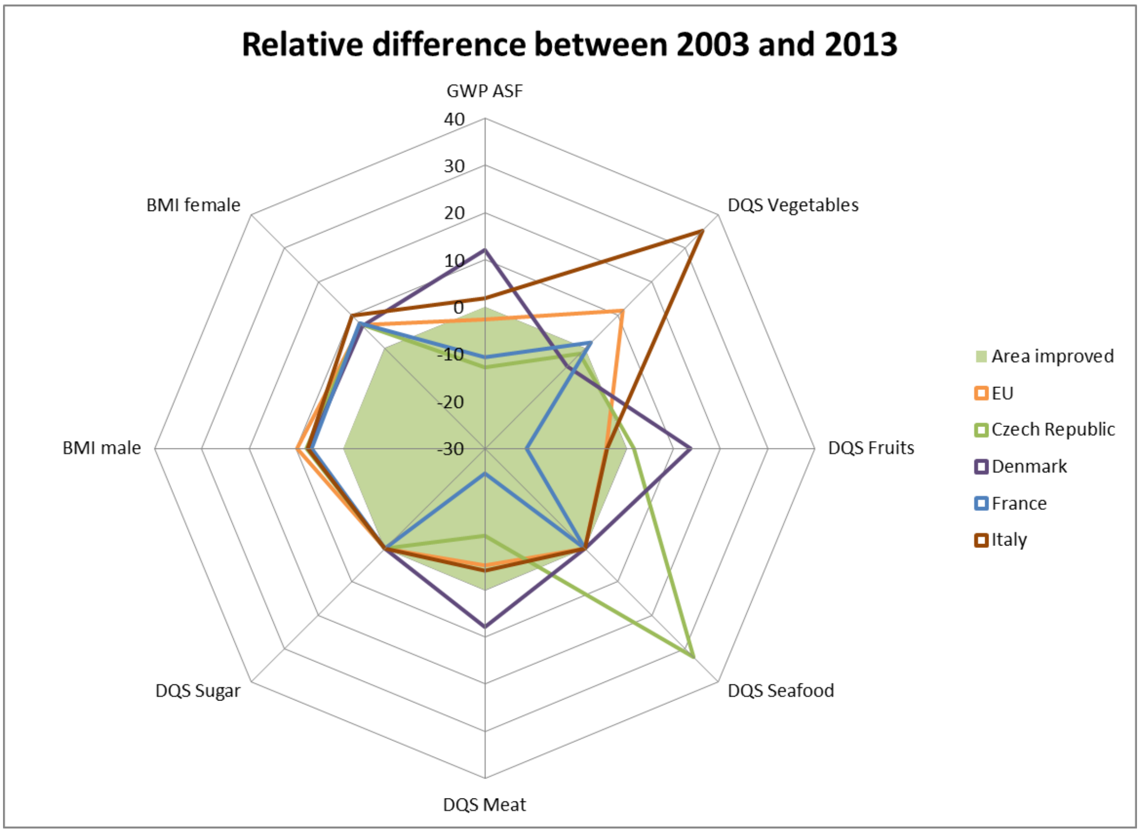
Table 6: Dietary quality score foods: five selected food items standardised for 2000 kcal/d.

	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

Food supply data for each of the five key foods were based on FAO food supply data for the year 2003 and 2013 (2013 is the latest data available from FAOSTAT). Although the FAO food supply data do not represent actual intake by consumers at the time of writing we did do not have the EFSA data at hand for two time periods. As thought experiment we thus rely on the FAO dataset for which time series are readily available. Based on the FAO supply data we calculated a score for each key food for the four selected European case study countries (Czech Republic, Denmark, France and Italy) and compared the score for each key food in 2003 to the score in 2013.

The performance metrics 'energy balance' was based on the body mass index (BMI). Information on the BMI for males and females with an age above 18, were derived from the World Health Organisation. We focused on the percentage of people with a BMI above 25, i.e. people that are overweighed or obese. BMI was calculated for the four case study countries and 2013 BMI scores for male and female were compared to the scores in 2013.

The performance metric 'climate stabilisation' centres around global warming potential (GWP) expressed in CO_2 equivalents. We focused on the supply of ASF as ASF products account for large part of the environmental impact of our diets. Food supply data for the five main ASF products (see D4.1) – beef, chicken, eggs, milk, and pork - were based on FAO food supply data for the year 2003 and 2013 (2013 was again the latest data available). The supply data were multiplied the GWP data. GWP data were based on a recent review from Clune et al. (2017). Again GWP for the five ASF products were calculated for the four case study countries and the GWP for each ASF product in 2003 was compared to the score in 2013. This relative score was averaged over the five ASF products to reach a GWP score by case study country.



Note: DQS=dietary quality scores

Figure 3: Example of a spider diagram presentation over different metrics, relative difference between the years 2003 and 2013 (the green area is the improved area)

Figure 3 presents the results of this illustration of how the SUSFANS metrics can provide an assessment across policy goals. The green area is the area of improvement. For GWP related to ASF products we see in France and Czech Republic a decrease, meaning that the climate impact of ASF products in diets decreased in 2013 compared with 2003. In Denmark and Italy, however, we see the opposite development with an increase impact of ASF consumption on GHG emissions.

For the five dietary quality scores (DQS) we see no improvement/increase related to vegetables in any of the countries, while DQS for fruit improved in Italy and France between 2003 and 2013. We see no improvement for the DQS related to seafood and sugar. Related to the DQS of meat we see an improvement in France and Czech Republic and a small improvement in Italy. This is consistent with the GWP results: showing that Denmark is the only country in which ASF supply increased while in the other countries it decreased.

7.2 Insights gained from the illustrative experiment

Although the (consumption) data in the assessment above is based is clearly limited, working through a concrete example provides useful insights to further develop the SUSFANS approach to measuring the impacts of European diets.

In D5.4 actual assessments will be performed on the contribution of an innovation in reaching a policy goal defined in D5.2 and D5.3. The starting point for the assessments in D5.4 will be a baseline situation/current situation similar to the use of 2003 in the experiment above. The results of the assessment in D5.4 will also be presented in a spider diagram to show the impact across a variety of metrics.

The spider diagram can, however, be presented in several ways. In the illustration above we expressed the results of each performance metrics relatively, to make it possible to present all the results together in single figure. The disadvantage of this approach is that the actual data are lost in the final figure. For example, from the spider diagram you cannot see whether the actual contribution in CO_2 equivalents from ASF is higher in Denmark compared to France, you can only see the change in performance of a certain country (i.e. if they are producing with less emissions than before). The aim of the study should determine how the spider diagram is presented, while aiming for consistency among SUSFANS papers. If the aim of a study is, for example, to illustrate the actual impact of a country on climate change, absolute numbers should be used instead of relative numbers. If absolute number are used, however, one should consider to have a different scale for each performance metric making it harder to read the figure.

In the spider diagram (Figure 3) we showed an environmental performance metrics based on one individual variable. This is, however, often not the case, meaning that weighing is needed. Weighing of individual variables will have a large effect on the final results and generally has no clear and undisputed basis. Is radiative forcing more important than CO2-equivalence one can wonder for example.

Showing all performance metrics in one spider diagram means that data will be aggregated meaning that details are lost in the final presentation. For the assessments in D5.4 it is extremely important to consider the robustness of the results, and where possible to perform sensitivity analysis. For example assessing the impact of weighing scheme on the conclusion, or checking if the conclusion holds at more disaggregate level as well. While being accessible and showing trade-offs across different goals, a pitfall of the spider diagram presentation is the possibility of drawing conclusions not fully capturing the complexity of the underlying system and thus missing important trade-offs elsewhere in the food system.

In this illustrative experiment we did not include the policy goals or policy targets simultaneously developed with this current deliverable in D1.3. Increasing the aggregation level to the policy goals in the spider diagram allows a presentation close to the policy-making process, but also obscures potentially important details about the food system. A balance has to be struck between accessibility of results while doing justice to the complexity of the food system. The assessment of innovations in D5.4 will allow further exploration of how to find such balance. Here we will compare the current situation with the potential situation in which an innovation is applied and show the potential contribution of an innovation in reaching a policy target.

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APPENDIX

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

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

Table 2. 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)

Table 3. 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	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 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 (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

Table 4. 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}, ${}_{x}T_{iwt}$, 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)	

Table 5. 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	