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The role of dairy and plant based dairy alternatives in sustainable diets

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Foreword

Sustainable diets that are nutritionally adequate, environmentally sound, economically viable and socially and culturally acceptable are gaining increasing attention. The focus has long been on the role of meat and its association with high environmental pressures, especially greenhouse gas emissions, and its detrimental health effects at high consumption levels. Much less attention has been paid to the role of dairy products in sustainable diets. There is currently a rise in plant-based dairy alternatives, e.g. drinks, yogurt-like products, spreads, ice-cream etc. made of soy, legumes, seeds, nuts or cereals. These have potentially lower negative impacts than dairy products but different nutritional profiles, which raises concerns about their role as replacements or complements to dairy products in sustainable diets. These concerns form the background to this report.

As a researcher at the Swedish University of Agricultural Sciences (Elin Röös) and director of the Food Climate Research Network (FCRN) (Tara Garnett), for some years we had spoken about a need to investigate dairy and plant-based dairy alternatives in diets more specifically and thoroughly. During summer 2017, we contacted the Danone company for another reason (looking for data for a LCA on instant baby formula) and ended up in a broader discussion on the topic of dairy and plant-based dairy alternatives. Danone had recently acquired several leading plant-based brands (Silk, Vega, Alpro etc.) and nutritionists and environmental managers from both the dairy and the plant-based alternatives side were asking the same question as us researchers: What are the respective roles of dairy and plant-based dairy alternatives in sustainable diets when health, environmental, ethical and social concerns are taken into account? The purpose of this report is therefore to describe the state of current research on the broad topic of sustainable diets, dairy and plant-based dairy alternatives, as a basis for development of a research roadmap to address this research question.

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Uppsala, 16 July 2018 London, 16 July 2018

Elin Röös Tara Garnett

Summary

Current food systems are responsible for approximately one-quarter of anthropogenic greenhouse gas (GHG) emissions and are a leading cause of deforestation, biodiversity loss, freshwater use and water pollution. They are also insufficiently effective at feeding people adequately; malnutrition in all its forms (hunger, obesity and micronutrient deficiency) affects about one-third of the world's population. At the same time, food systems reflect and exacerbate inequalities and abuses of power at all levels (international, national, societal, sectoral and familial), while the treatment of farm animals reared for food and draught purposes raises serious ethical questions.

There is mounting evidence that a shift towards more sustainable food systems and diets is necessary and will require profound changes in how and what food we produce and how and what we consume. This report summarises the current scientifically-grounded state of thinking on what such a shift might comprise, with particular focus on sustainable diets. More specifically, it considers the respective roles of dairy and plant-based dairy alternatives in sustainable diets. Dairy products currently deliver many important nutrients to large population groups and are highly appreciated. However, rearing ruminant animals is associated with important negative environmental impacts such as high GHG emissions and large land requirements. Plant-based dairy alternatives based on soy, legumes, seeds, nuts or cereals are now on the market and there is increased interest and demand for such products in many countries. Functionally, these could replace and complement dairy products in the human diet, potentially reducing the environmental impact of food consumption. However, since dairy products and plant-based dairy alternatives differ in their nutrient composition and health impact, the nutritional aspects of such a switch need to be considered.

What is a sustainable diet and how can it be measured?

One of the most commonly cited definitions of sustainable diets comes from FAO/Biodiversity International (2010) and reads as follows:

"Sustainable diets are those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources."

This definition, as well as definitions from other organisations, all acknowledge the multifaceted aspects of sustainability, including social, economic and environmental aspects. Other definitions also raise the issue of animal welfare, feasibility of diets and the aspect of good quality food.

To make progress towards sustainable diets, a way to concretise and measure the sustainability of diets is needed. Several authors provide frameworks that describe components of sustainable foods or diets, but only a few propose concrete indicators on how these aspects should be evaluated and quantified and the results displayed. Most current literature on healthy and sustainable diets commonly only includes one or a few aspects of sustainability, hence potentially failing to capture both important synergies and goal conflicts. A systematic review of such studies by Jones et al. (2016) shows that to date, the most commonly used metrics to evaluate the sustainability of diets are GHG emissions and land use. This lack of multidimensionality is understandable considering the complexity of assessing multiple impacts of a large range of foods and the lack of data. That said, rapid progress is being made in this field.

In order to make indicators practically tangible and to relate outcomes to sustainability targets, there is a need to define threshold levels of e.g. health and environmental sustainability, i.e. a level beyond which a system can be said to be unsustainable. Weighting of different sustainability indicators is also needed if the results are to be presented as an aggregate score in order to enable comparisons among products or diets. Thresholds and weighting methods will inherently reflect values and norms. Different weighting strategies have been developed, including the distance-to-target approach and panels of experts or civilians. The distance-to-target approach assesses how far a target is from being achieved and distributes weights to different aspects accordingly. It has become increasingly popular to relate indicator results to global targets such as the Planetary Boundaries (Rockström et al., 2009; Steffen et al., 2015), but much more work is needed in this area.

How do dairy products and plant-based dairy alternatives compare in terms of nutrition and health?

Dairy milk and plant-based alternatives differ in important nutritional ways, although their energy content is fairly similar if low-fat dairy milk is used as the basis for comparison. Plant-based drinks are generally lower in protein (<1%) and fat (<1.5%), but have a similar amount of carbohydrates as milk (3-5%). The exceptions are oat drinks, which contain considerably more carbohydrates (~7%), and soy drinks, which contain protein in similar amounts to milk (3-4%), although there are slight differences in protein digestibility and amino acid profile. As regards micronutrients (vitamins and minerals), the similarity between dairy and plant-based alternatives is entirely dependent on whether the latter are fortified or not.

Moving from nutrients to health outcomes, epidemiological studies on intake of dairy products and plant-based dairy alternatives show some clear positive health effects for dairy products (e.g. lowered risk of type 2 diabetes from low fat and fermented dairy products) and for fortified soy-based products. There is very little or no literature on the long-term health effects of non-soy plant-based dairy alternatives specifically, however studies on the raw material itself show some health benefits (e.g. for oats and almonds).

How do dairy products and plant-based dairy alternatives compare in terms of environmental impacts in a product-to-product comparison?

The environmental impacts of foods are commonly compared on the basis of mass using life cycle assessment (LCA), which is a well-established quantitative, standardised method for assessing the environmental impact of goods and services. Many LCA studies have investigated the GHG emissions from dairy production. Surprisingly, no equivalent studies for plant-based dairy alternatives have been published in scientific journals, but some LCA studies are reported in the grey literature. There is also some literature on the environmental impact of the raw materials used in several plant-based dairy alternatives, making it possible to draw some conclusions regarding the environmental impacts of the finished products. Based on the available literature, dairy products generally have a higher environmental footprint per unit mass than plant-based dairy alternatives when it comes to GHG emissions, total land use (not considering the type of land), energy use, nitrogen footprint, eutrophication and acidification potential. Dairy milk production uses more water than soy and oat drinks, but less than almond drink. For biodiversity impacts more research is needed, especially the need to consider the positive impacts that grazing animals provide in some circumstances. In general, there is a need for more systematic comparisons of dairy and plant-based dairy alternatives, as it is difficult to draw solid conclusions when comparing results from different studies.

Comparisons of the environmental impact on the basis of nutritional content, using a nutrient density index rather than mass as the unit of comparison, yield variable results depending on how the index is constructed. If fortified plant-based dairy alternatives are used in the comparison, these seem to score better in terms of combined nutritional and environmental aspects than dairy products, but more studies are needed to confirm this. Aspects of protein quality and digestibility were included in a study by Sonesson et al. (2018) comparing milk, chicken, pork, bread and pea soup. Milk had the highest climate impact of all these products when protein quality and digestibility were not considered. The difference between milk and the other products decreased when protein quality and digestibility were included, due to the beneficial amino acid profile and slightly higher protein digestibility of milk. However, its impact was still considerably higher than that of the two plant-based options.

How do dairy products and plant-based dairy alternatives compare in a dietary context?

Comparing foods on a per product basis is of limited value for determining the health outcomes or environmental impact of eating patterns, as it is the total impact of all foods in the diet that determines overall outcomes. Numerous studies assessing the potential effects of reducing meat and/or dairy in the diet and replacing them with plant foods show considerably lower climate impact and land use from vegetarian or vegan diets. Only a few studies have specifically investigated the effects of substituting dairy partially or completely in the diet, i.e. without also considering meat. Two studies found reductions in land use and GHG emissions when dairy was replaced with plant-based foods, with varying effects on diet quality depending on the substitute food, while one study found little or no environmental benefit in terms of GHG emissions and land use.

More research is needed on how realistic replacement of meat and of dairy affects the nutritional and environmental outcomes for different groups of consumers in different countries, in order to establish the role that dairy and plant-based dairy alternatives can play in sustainable diets. Basically, two approaches, simulation and optimisation studies, can be applied.

Simulation studies tend to replace animal products with plant-based foods by mass, isocalorically or on the basis of protein content, in some cases based on assumptions as to what a normal and culturally acceptable substitute might be (e.g. replacing cheese with peanut butter, chocolate spread or jam in the Dutch diet). These studies tend to show favourable outcomes for intake of saturated fats and fibre, but highlight risks of deficiencies of some micronutrients at high substitution rates.

Optimisation studies use mathematical models to determine nutritionally adequate diets at lower environmental (e.g. GHG) cost, while often seeking to keep diets as culturally 'normal' as possible. In such cases, the meat content of the diet declines but use of dairy products often remains similar to current levels, due to their high calcium content and popularity, and thus cultural non-negotiability.

What we know and what are the most important further research needs?

Assessing the sustainability of diets is a highly complex undertaking due to the multitude of sometimes competing concerns inherent in food production and consumption. Individual research fields have contributed knowledge of different parts of this complex picture. For example, the field of diet-related health research is vast and has provided overarching and generally accepted principles of what constitutes a healthy dietary pattern. Studies on the environmental impact of food have shown that animal-based products generally generate higher negative impacts than plant-based products. However, these guiding principles have to be broken down even further to apply to different dietary contexts and population subgroups, and have to be considered alongside aspects such as diet acceptability and what can be realistically changed. Promising initial attempts have been made to gather several aspects of sustainable diets into indicator-based frameworks, in order to provide a way of considering a multitude of issues and their trade-offs in different types of decision making. More work is needed in this area to make indicators and frameworks for assessing the sustainability of diets more robust, transparent, relevant and useful. To enable constructive discussions and sound decision making, such frameworks have to distinguish, as clearly as possible, between scientific 'facts' and normative decisions (choice of indicators, thresholds and weighting methods). Complexity will inevitably increase with the number of issues included, which is why trade-offs between comprehensiveness and comprehension – i.e. the completeness of the information, as opposed to our ability to make sense of and act on that information – have to be resolved.

Research shows some clear positive health effects for dairy products and for soy-based products. For other plant-based dairy alternatives, there is very little or no literature on their long-term health effects, although there is evidence of positive outcomes for some of the raw materials from which they are made. As regards the environmental impacts of dairy products and plant-based alternatives, the current literature indicates that the environmental impact of dairy milk from industrialised Western systems is higher than that of plant-based dairy alternatives within most impact categories. However, the comparison rests on somewhat shaky grounds, as studies on plant-based dairy alternatives have not yet been published in scientific journals and as different studies use different methodologies. In order to draw solid conclusions, milk and the full range of plant-based alternatives need to be compared within the same study, using the same methodological choices and applying comprehensive sensitivity analysis.

The limited existing research on replacement of dairy products with different types of plant-based dairy alternatives indicates that the respective benefits of these products are context-specific. More modelling studies are needed to test a broad set of consequences of including dairy products, a range of different plant-based alternatives or combinations of these in different dietary contexts for different types of consumers. To make these studies as relevant as possible, more research is needed on how people actually, rather than potentially, change their eating patterns when aiming for a less environmentally damaging and healthier diet.

Finally, what people eat naturally affects what is produced, which in turn affects landscapes and rural societies. Such socio-economic effects are highly challenging but vital to capture, which is why methods that enable inclusion of socio-economic issues in sustainability assessments urgently need to be developed.

Table of contents

Foreword 1

Summary 3

1. Introduction 10

2. Food system sustainability 13
- 2.1 Food system challenges 13
- 2.2 Solutions to decrease environmental pressures on food systems 15
- 2.3 Food system solutions to improve public health 18

3. Measuring sustainability and health 20
- 3.1 Sustainability and sustainable development 20
- 3.2 Sustainability assessment tools 22
- 3.3 Health indicators at individual level 26
- 3.4 Health indicators at food and diet level 28

4. Sustainable diets 31
- 4.1 Definitions of sustainable diets 31
- 4.2 Frameworks for sustainable diets 32
- 4.3 Frameworks for sustainable food systems 39
- 4.4 Studies measuring specific aspects of sustainable diets 42
- 4.5 Methods for indicator weighting and diet optimisation 45
- 4.6 Defining rating systems and thresholds for sustainable diets 48
- 4.7 A ‘livestock-on-leftovers’ approach to sustainable diets 53
- 4.8 Dietary guidelines and sustainability 56
- 4.9 Norms, views and perspectives on sustainable diets 58

5. The role of dairy and plant-based dairy alternatives in sustainable diets 60
- 5.1 Health effects of dairy and plant-based dairy alternatives 61
  - 5.1.1 Nutritional content 62
  - 5.1.2 Health effects 70
  - 5.1.3 Authorised health claims 72
  - 5.1.4 Fortification of dairy and plant-based drinks 72
- 5.2 Environmental impacts of dairy and plant-based dairy alternatives 73
  - 5.2.1 Comparison on a product-to-product basis 74
  - 5.2.2 Comparison in a diet context 87
  - 5.2.3 Comparison from a production system perspective 93

6. Conclusions and further research needs 95

References 98

Appendix A. Frameworks for sustainable development 109

Appendix B. Conceptual frameworks for food systems 115
Appendix C. More on metrics and indicators 120
Appendix D. Review of sustainable diet indicators - an update of Jones et al. 127
Appendix E. Examples of currently used indicators for sustainable diets 129
Appendix F. Sustainable dietary recommendations 136
Appendix G. Fortification 140

References to the appendices 143

1. Introduction

Current food systems are responsible for approximately one-quarter of anthropogenic greenhouse gas (GHG) emissions and are a leading cause of deforestation, biodiversity loss, freshwater use and water pollution. However, food is essential for human survival and an important part of 'the good life', while also at the heart of the discourse on achieving a sustainable society. Despite massive investments and developments in food production, current food systems are unable to adequately feed everyone, as malnutrition in all its forms (hunger, obesity and micronutrient deficiencies) affects about one-third of the world's population.

Dairy products are nutrient-dense, highly appreciated and in many countries a common product in human diets, consumed on a daily basis. Grazing animals can contribute positively to certain environmental aspects by preserving high nature value pastures and converting non-human edible biomass into meat and milk. However, rearing ruminant animals is also associated with large emissions of GHG and high land and water use, as well as other negative environmental impacts which are highly variable depending on production practices.

An increasing number of plant-based dairy alternatives based on soy, legumes, seeds, nuts or cereals are now on the market and there is increased interest and demand for such products in many countries. Available environmental assessments indicate that these products have fewer negative environmental impacts, but the picture is less clear when nutritional aspects are included, as the nutritional content of plant-based dairy products differs in terms of both macro- and micronutrients. This also complicates comparison between dairy and plant-based alternatives and makes the dietary context, i.e. the diet in which they are consumed, highly important for the outcome. Furthermore, sustainability encompasses many aspects in addition to health outcomes and environmental impacts of foods, such as social and cultural aspects, that have not been extensively studied to date.

This report summarises current knowledge and research regarding the concept of sustainable diets and ways to measure it. In particular, it examines the role of dairy and plant-based dairy alternatives in sustainable and healthy diets. The aim is to provide background for a broad audience of food sustainability stakeholders from different backgrounds and scientific fields. Therefore, the report provides a broad overview of relevant issues when assessing the sustainability of diets, rather than a detailed analysis of any specific aspect. Due to the breadth and complexity of the subject and the rapid developments in this area, the report does not claim to be exhaustive.

The main focus of the report is on *sustainable diets*, rather than sustainable food systems, foods, farms or companies. However, diets are an integral part of food systems, interacting with all other parts directly or indirectly, and thus a clear-cut division between sustainable diets, the foods themselves and other food system components is not possible. Fig. 1.1 shows a simple conceptual diagram of the food system, to illustrate how diets make up one (of several) 'objects of assessment' when studying the aggregated sustainability of food systems.

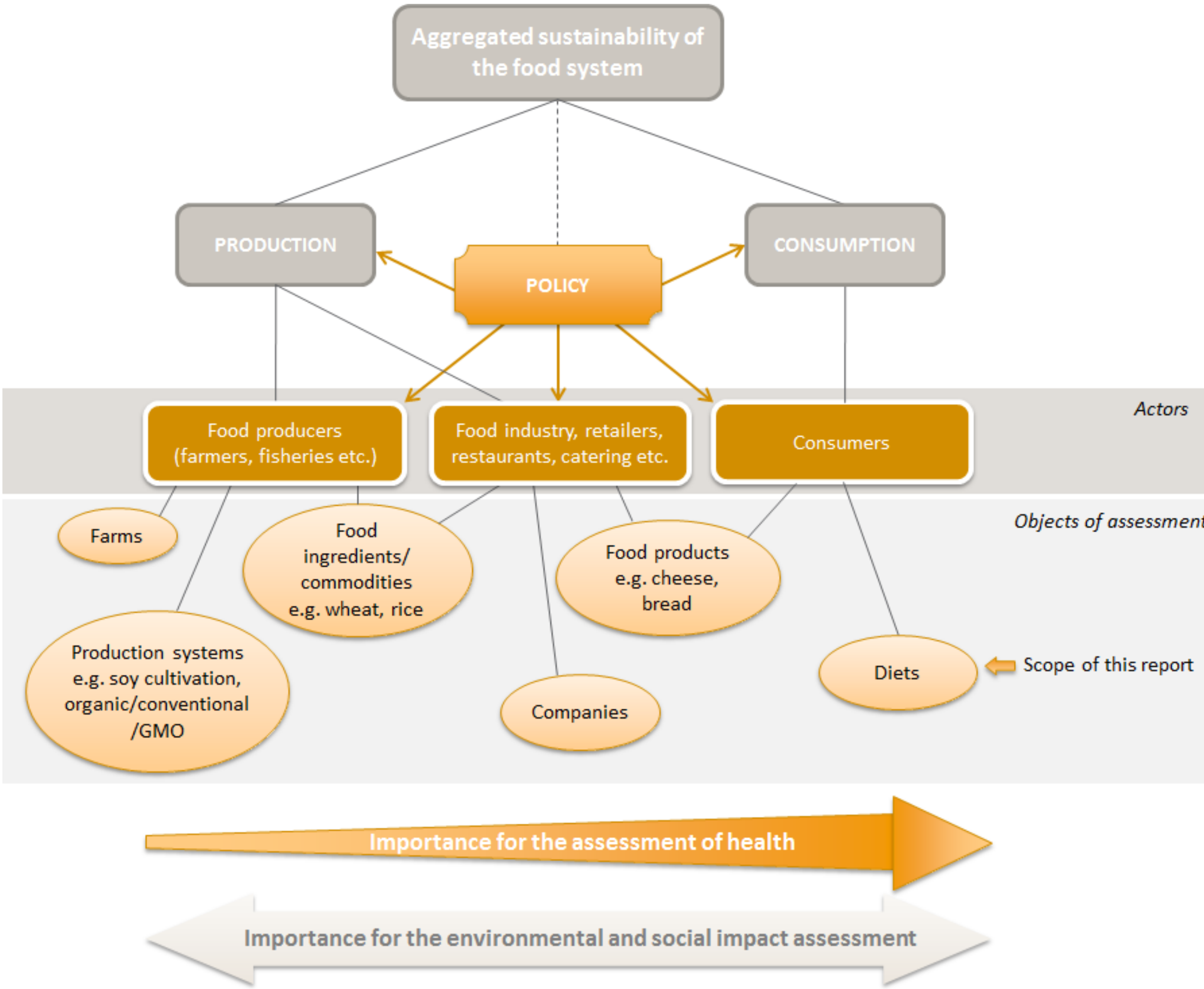

Fig. 1.1. Conceptual picture of the food system. The scope of this report is 'Diets'.

At an aggregate level, a sustainable and healthy food system includes both consumption (what and how much that is eaten) and production (how food is produced). At a global level, these come together, but at a national/regional/local level they are often not fully connected due to trade. There are several different actors in food systems. On the production side are food producers (farmers, fisheries etc.), the food industry, retailers, restaurants etc. On the consumption side are consumers. Policy (in the centre of Fig. 1.1) needs to influence all these in order to improve production and steer consumption. Connected to the different actors are several '*objects of assessment*', i.e. the sustainability of farms, companies, production systems, food ingredients, food products or diets can be assessed. As can be seen, diets are just one entry point from which to study food systems.

Although the focus of this report is on sustainable diets as an object of assessment, in order to provide some context Section 2 takes a look at the impacts of food systems as a whole, some proposed solutions and the magnitude of these. Section 3 provides a brief overview of the concepts of sustainability and health in general and ways to measure progress towards these. We then turn to the main topic of this report; *sustainable diets*. Section 4 reviews current definitions, frameworks and indicators of sustainable diets. Section 5 exemplifies and attempts to summarise research specifically on the role of dairy and plant-based dairy alternatives in sustainable diets, looking at these from three different perspectives: on a product-by-product basis, in a dietary context and from a production/landscape perspective. Section 6 presents key conclusions from this review of the literature and highlights further research needs.

2. Food system sustainability

2.1 Food system challenges

At present, food systems[1] are failing to deliver healthy diets for all and are a major driver of negative environmental impacts.

Starting with environmental pressures, the Planetary Boundaries developed by Rockström et al. (2009) refer to nine crucial boundaries for Earth system functioning (Fig. A1 in Appendix A). An update of the concept by Steffen et al. (2015) concluded that four of the nine Planetary Boundaries have now been breached: climate change, loss of biosphere integrity, land-system change and altered biogeochemical cycles (phosphorus and nitrogen flows). Two of these, climate change and biosphere integrity, are what the scientists call 'core boundaries'. Significantly altering either of these core boundaries would "*drive the Earth system into a new state*". Professor Will Steffen, lead author of the study, states:

"Transgressing a boundary increases the risk that human activities could inadvertently drive the Earth System into a much less hospitable state, damaging efforts to reduce poverty and leading to a deterioration of human wellbeing in many parts of the world, including wealthy countries [...]"

For public health, the most pressing challenge in high-income settings has long been non-communicable diseases (NCDs), i.e. cardiovascular diseases, cancer, chronic respiratory diseases and diabetes. This is reflected in the United Nations (UN) Sustainable Development Goal (SDG) 3.4: "[...] *by 2030, reduce by one third premature mortality from NCDs through prevention and treatment*". In 2015, NCDs were responsible for 40 million deaths, representing 70% of all deaths worldwide. A large proportion of these deaths were premature; they included over 15 million people between the ages of 30 and 70, representing 38% of NCD deaths and 27% of all global deaths (WHO, 2017). Four lifestyle factors are considered to be the most important contributors: tobacco smoking, alcohol use, physical inactivity and unhealthy diets. NCDs are not just diseases of the affluent, e.g. in 2008, roughly four out of five deaths caused by NCDs occurred in low- and middle-income countries (WHO, 2011a). Malnutrition can be divided into 'undernutrition' i.e. the burden of hunger and undernourishment, and 'overnutrition', i.e. the burden of overweight and obesity. Many countries are now struggling with both these problems simultaneously, while micronutrient deficiencies impose an additional burden. Micronutrient deficiencies in relation to undernutrition have been a known challenge for some time, while the public health community is now also forced to address the role of micronutrient deficiencies in

[1]The High Level Panel of Experts on Food Security and Nutrition (HLPE) has adopted the following definition (HLPE, 2014): *"a food system gathers all the elements (environment, people, inputs, processes, infrastructures,institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food, and the output of these activities, including socio-economic and environmental outcomes"*. Several conceptualisations of 'food systems' have been presented by different authors. For an overview, see Appendix B.

individuals who are supposedly 'overnourished'. Individuals with obesity have been recorded to have lower levels of a wide array of micronutrients, a factor which may play a role in the development of obesity-related diseases (Via, 2012). Food systems also struggle with a range of other social challenges, such as exploitation of farm workers, land grabbing, uneven power structures among food system actors etc.

Gordon et al. (2017) developed a framework based around the Planetary Boundary concept to illustrate and quantify the effect of food systems on health (including undernourishment and overweight), the food system (including food safety, nutrition and volumes) and the biosphere (land system change, biodiversity, climate change, biochemical flows, persistent pollutants and water) (Fig. 2.1). By 2015, both biodiversity and biogeochemical flows exceeded Planetary Boundaries of land system and climate change, with land system change being pushed into the zone of uncertainty by food systems alone and with an estimated 25% of climate change being driven by food systems.

In terms of food supply, food systems now produce enough food to feed the global population, but struggle to provide adequate nutrition for all. In 2016, 815 million people, or one in nine, were undernourished, while in 2014, 600 million people were obese (FAO, 2017a). Overweight and obesity now cause more deaths than underweight (WHO, 2009). According to Forouzanfar et al. (2015), the most important risk factors for loss of disability-adjusted life years (DALYs) are now reported to be 'dietary risks', such as low fruit and vegetable intake, high intake of sodium, low intake of whole grains and low intake of nuts and seeds.

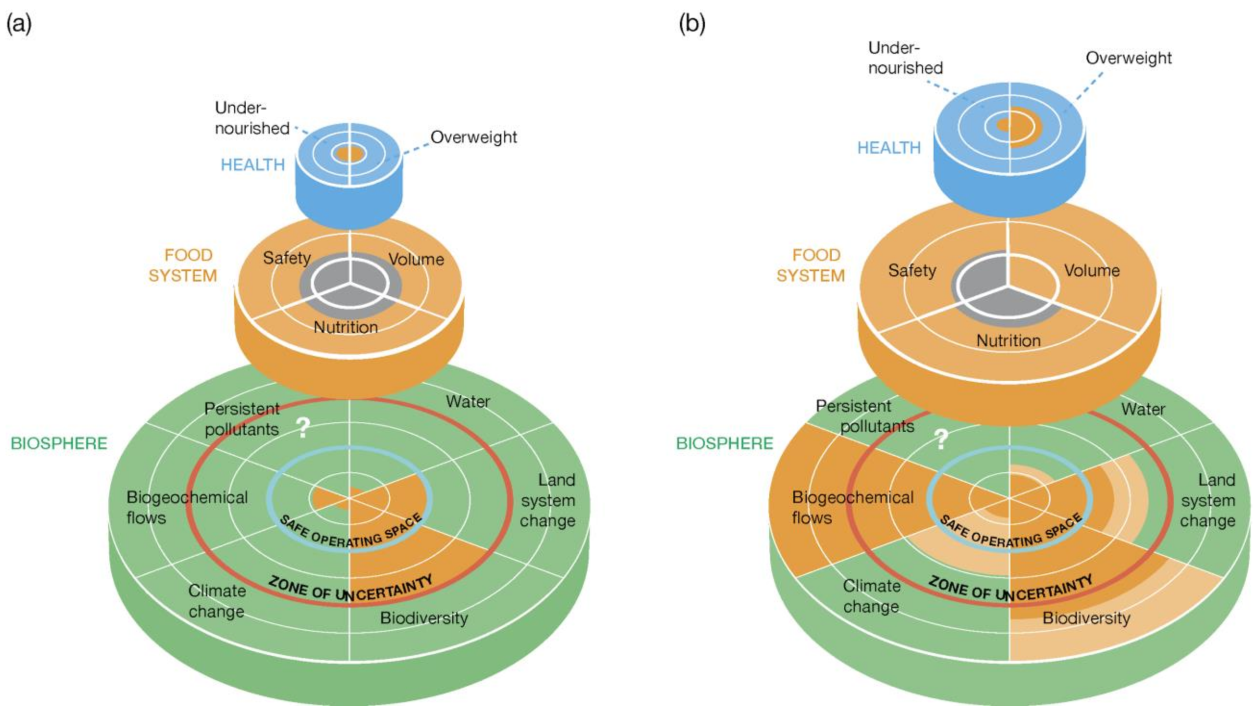

Fig. 2.1. The food system and its impact (in dark orange) on health and the biosphere, comparing (a) 1961 and (b) today. From Gordon et al. (2017).

2.2 Solutions to decrease the environmental pressures of food systems

There are basically four overarching ways to decrease the environmental pressures of food systems (after Bryngelsson et al., 2016):

1. Increases in productivity and efficiency, i.e. producing more food with fewer inputs of e.g. energy, land, water and nutrients.
2. Implementation of technological solutions, e.g. manure storage that limits methane emissions or improved management practices such as well-designed crop rotations to minimise the use of pesticides.
3. Dietary change towards foods with lower impacts.
4. Reducing losses and waste in all steps.

Recent research shows that, without a combination of all these approaches, environmental targets, e.g. the Paris Agreement on climate change, are unlikely to be reached (Bajzelj et al., 2014; Bryngelsson et al., 2016; Röös et al., 2017). However, prioritisation among mitigation options will largely be determined by stakeholders' values and perspectives on the feasibility and legitimacy of different approaches, and whether technological approaches should be prioritised over behaviour change and consumption shifts, or vice versa (Garnett, 2015; see also section 4.9).

Smith et al. (2008) assessed the mitigation potential in terms of lowered GHG emissions from agriculture through improvements in production. They concluded that the total technical/biophysical mitigation potential is within the range of current emissions from agriculture (5-6 Gt CO_2e), but that achieving this technical potential will be highly challenging due to economic and legal barriers. For countries where agriculture is already industrialised, the mitigation potential achievable via further efficiency gains and implementation of new technologies is more limited. For example, the Swedish Board of Agriculture has estimated that emissions of GHG from Swedish agriculture could potentially be reduced by 20% by 2050 through management and technical improvements (SBA, 2012). Mitigation potential also exists beyond agriculture and across the food system, but this potential has not been quantified. Strategies include increased efficiency in processing and use of renewable energy. Niles et al. (2018) provide a review of climate change mitigation options across the food system.

Hallström et al. (2015) performed a systematic review of GHG emissions and land use from dietary change and concluded that, in areas with affluent diets, GHG emissions and land use can be reduced by up to 50% through a change to diets containing fewer animal products. Aleksandrowicz et al. (2016) concluded that, by adopting more sustainable dietary patterns, reductions as high as 70-80% of GHG emissions and land use, and 50% of water use, are possible. As regards waste reduction, Bajzelj et al. (2014) show that globally, a 50% reduction in waste could lower GHG emissions from agriculture by 22-28% and cropland use by 14% compared with baseline levels.

Bryngelsson et al. (2016) assessed combined technical advances, waste reductions and dietary shifts[2] in a study in a Swedish context (Fig. 2.2), and concluded that technical advances can play a major role in mitigating GHG emissions. Under optimistic assumptions, they found that emissions of methane and nitrous oxide could be reduced by 50% by 2050, although this alone would not be sufficient to meet European Union (EU) climate targets. Large reductions (>50%) in ruminant meat consumption were found to be essential if climate targets are to be met.

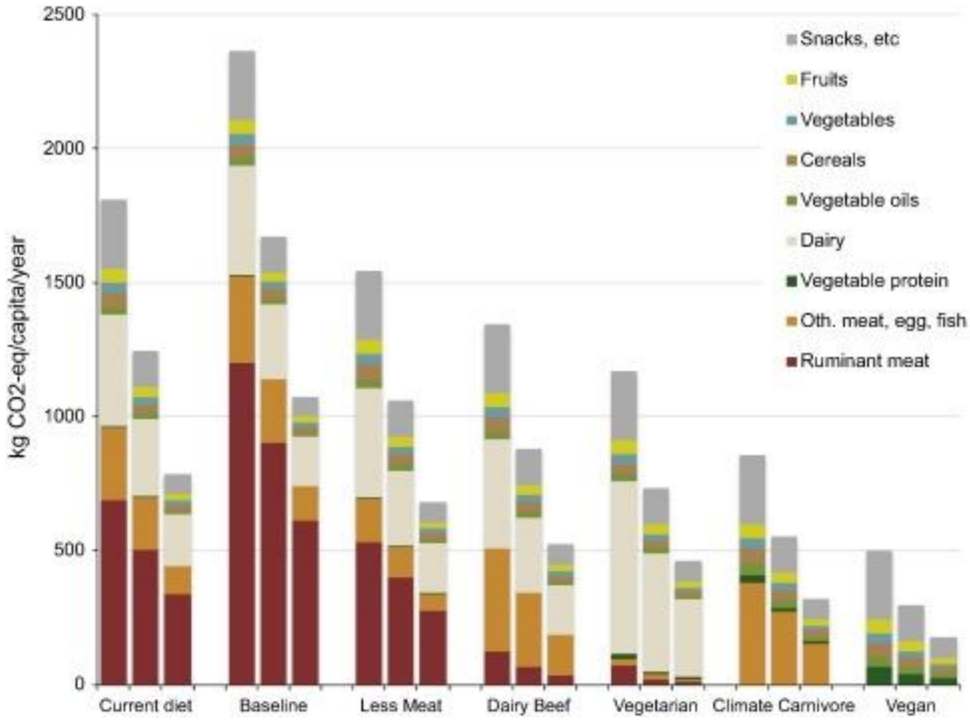

Fig. 2.2. Greenhouse gas emissions (by food type) per capita by diet and technology level. For each diet, emissions are shown for the current technology (left), moderate technology advances (middle), and optimistic technology advances (right). From Bryngelsson et al. (2016).

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[2]Description of the seven scenarios in Bryngelsson et al (2016): *Current diet* corresponds to average consumption per capita in Sweden in 2013. *Baseline* is continued development of current and recent trends of increasing meat consumption at the expense of dairy products and carbohydrate-rich food. *Less Meat* is based on baseline developments, but with all meat consumption (including fish and eggs) decreased by 50% and legumes, oil, and cereals increased. *Dairy Beef* is based on baseline developments, but all beef except that from the dairy sector is replaced by poultry meat, which gives about 80% lower ruminant meat consumption than the baseline. In the *Vegetarian* scenario, meat is replaced by legumes, eggs and significant quantities of cheese. Beef from culled dairy cows is also included in the Vegetarian scenario but, in contrast to the Dairy Beef scenario, surplus dairy calves are culled at birth. *Climate Carnivore* does not include any ruminant products. The total meat consumption is equal to Baseline, but ruminant meat is replaced by poultry and dairy products are replaced mainly by soymilk, but also by vegetable oils. Finally, the *Vegan* scenario does not include any animal products. Dairy products are replaced by soy products and vegetable oils. Meat, eggs and seafood are replaced by vegetable sources of protein, mainly legumes, nuts and seeds. Bryngelsson et al. (2016) corrected diets for energy intake and macronutrient proportions to be within recommendations. However, they took a 'conservative approach' to nutrient adequacy and modelled diets to be similar to current diets, assuming unchanged preference for non-essential food items and protein and fat where still in excess as in current diets. Their study should therefore been seen as mainly looking at improving diets from a climate mitigation perspective, rather than a nutritional perspective.

A study by Röös et al. (2017) modelled different scenarios for food production and consumption based on different perspectives of the 'food system problem' (Garnett, 2015). The results indicated that production improvements, consumption changes and waste reduction must all be part of the transition to a sustainable food system in order to sustainably meet the growing demand for food for an increased population by 2050. Table 2.1 shows the global reduction potential of different mitigation options in that study. Trade-offs and challenges with different options are also highlighted and discussed by Röös et al. (2017), for example trade-offs in animal welfare, increased risk of point pollution and use of antibiotics from livestock intensification.

Table 2.1. Reduction (%) in global land use and greenhouse gas (GHG) emissions from agriculture under different mitigation scenarios compared with a business-as-usual scenario. From Röös et al. (2017)

Mitigation option	**Reduction in land use**	**Reduction in GHG emissions**
Food waste reduced by 50%	11%	9%
Yield gaps closed by 50%	15%	1%
Livestock intensification[1]	31%	22%
Livestock intensification[1] and dietary shift to a healthy diet[2]	45%	46%
Dietary shift to plant-based projected diet[3]	64%	73%

[1]Livestock production globally assumed to intensify to current levels of intensive production in North-Western Europe.
[2]Vegetable and fruit consumption set to 123 and 119 kcal per person per day, respectively, in all world regions. Sugar content capped at 150 kcal per person and day, and vegetable oil at 360 kcal for regions with projections that exceeded that level. Consumption of red meat capped at 57 kcal per person per day, poultry at 161 kcal, egg at 50 kcal and dairy at 300 kcal.
[3]Legumes and cereals isocalorically replace all animal products.

Other environmental pressures have been less studied, but some studies indicate positive outcomes from dietary shifts in other areas, apart from GHG emissions and land use. For example, Westhoek et al. (2014) showed that nitrogen emissions could be cut by 40% by a 50% reduction in consumption of meat, dairy and eggs in the European Union. For biodiversity outcomes, land sparing has been shown to be important (Balmford et al., 2015), strengthening the case for diets associated with low land use, but on-farm management and landscape characteristics are also important for biodiversity conservation (Bengtsson et al., 2005).

For mitigation strategies that involve financial gains, rebound effects (i.e. money saved being spent on other polluting activities) might offset considerable parts of the gains, and have to be carefully managed. Such effects have been documented e.g. for waste reduction strategies (Martinez-Sanchez et al., 2016).

2.3 Food system solutions to improve public health

In terms of public health, WHO (2016) outlines the following options for policies aimed at improving health and preventing NCDs:

- *"Promote and support exclusive **breastfeeding** for the first six months of life, continued breastfeeding until two years old and beyond and adequate and timely complementary feeding.*
- *Implement WHO's set of recommendations on the **marketing** of foods and non-alcoholic beverages to children, including mechanisms for monitoring.*
- *Develop **guidelines**, recommendations or policy measures that engage different relevant sectors, such as food producers and processors, and other relevant commercial operators, as well as consumers, to:*
    - *Reduce the level of salt/sodium added to food (prepared or processed).*
    - *Increase availability, affordability and consumption of fruit and vegetables.*
    - *Reduce saturated fatty acids in food and replace them with unsaturated fatty acids.*
    - *Replace trans-fats with unsaturated fats.*
    - *Reduce the content of free and added sugars in food and non-alcoholic beverages.*
    - *Limit excess calorie intake, reduce portion size and energy density of foods.*
- *Develop policy measures that engage food **retailers and caterers** to improve the availability, affordability and acceptability of healthier food products (plant foods, including fruit and vegetables, and products with reduced content of salt/sodium, saturated fatty acids, trans-fatty acids and free sugars).*
- *Promote the provision and availability of healthy food in all **public institutions** including schools, other educational institutions and the workplace.*
- *As appropriate to national context, consider **economic tools** that are justified by evidence, and may include taxes and subsidies, that create incentives for behaviours associated with improved health outcomes, improve the affordability and encourage consumption of healthier food products and discourage the consumption of less healthy options.*
- *Develop policy measures in cooperation with the **agricultural sector** to reinforce the measures directed at food processors, retailers, caterers and public institutions, and provide greater opportunities for utilization of healthy agricultural products and foods.*
- *Conduct evidence-informed **public campaigns** and social marketing initiatives to inform and encourage consumers about healthy dietary practices. Campaigns should be linked to supporting actions across the community and within specific settings for maximum benefit and impact.*
- *Create health- and nutrition-promoting **environments**, including through nutrition education, in schools, child care centres and other educational institutions, workplaces, clinics and hospitals, and other public and private institutions.*
- *Promote nutrition **labelling**, according to but not limited to, international standards, in particular the Codex Alimentarius, for all pre-packaged foods including those for which nutrition or health claims are made."*

The WHO report "*Fiscal Policies for Diet and Prevention of NCDs*" (2016) reviews the available evidence for economic tools with regard to diet. The strongest and most consistent evidence is available for taxes on sugar-sweetened beverages, which could reduce consumption by 20-50%, and subsidies on fruit and vegetables, which could increase consumption by 10-30%. The evidence is mixed on the net effect of fruit and vegetable subsidies on net caloric intake and weight, but overall diet quality improves, thus leading to improvements in health outcomes.

There is also growing evidence of the likely effectiveness of combinations of taxes and subsidies, particularly as a mechanism to reduce potential substitution with unhealthy foods.

A multitude of solutions for ending hunger have been documented (e.g. FAO, 2017b). For example, UN SDG 2 (zero hunger) concerns the need to increase investment in rural infrastructure, technology and agricultural research and to correct and prevent trade restrictions in world agricultural markets and maintain diversity in cultivated plants and domesticated animals. The High Level Panel of Experts on Food Security and Nutrition (HLPE) provides a comprehensive list of policy options for improved nutritional outcomes targeted across the whole food system (HLPE, 2017).

3. Measuring sustainability and health

3.1 Sustainability and sustainable development

The Brundtland commission, formally known as the World Commission on Environment and Development (WCED), was formed in 1984 in response to an urgent call from the UN to address the increasing deterioration of the environment, declining availability of natural resources and human inequality. Nine hundred days later, the report '*Our Common Future*' was released (WCED, 1987). The report is also known as the Brundtland report, after the WCED's chair, Gro Harlem Brundtland.

The report addressed the most pressing issues for humanity and outlined guiding principles for sustainable development, defining sustainable development as "*development that meets the needs of present generations without compromising the needs of future generations*". It also defined 'need' as a concept that prioritises the needs of the poor. The three pillars, or dimensions, of sustainability or sustainable development are sometimes mentioned in association with the Brundtland report, but the concept was in fact first mentioned at the World Summit of the UN General Assembly in 2005. Its resolution states:

"We reaffirm that development is a central goal in itself and that sustainable development in its economic, social and environmental aspects constitutes a key element of the overarching framework of United Nations activities."

A wide range of definitions and frameworks for sustainability and sustainable development have been developed within academia and by different organisations. The vagueness of the concept can be considered an advantage, as it has led to it being widely spread and accepted, but it can also be considered a disadvantage, as the concept risks being watered down if interpreted too freely. Appendix A summarises a few conceptual frameworks for sustainability and sustainable development.

The UN SDGs, the successors of the Millennium Development Goals (MDGs), are the most recent operationalisation of the concept of sustainability. They describe humanity's needs with clear goals and provide indicators to evaluate progress towards these goals. The recent FAO report *"Food and Agriculture - Driving Action Across the 2030 Agenda for Sustainable Development*" illustrates how all SDGs are in some way connected to food provisioning (Fig. 3.1). That report has a clear focus on eradicating hunger in low-income settings; the coupling of SDGs to food systems would look somewhat different in high-income settings, where the challenges are different.

Fig. 3.1. How food provisioning connects to the United Nations Sustainable Development Goals (SDGs). From FAO (2017b).

In a keynote speech at the Stockholm EAT Forum in 2016, Rockström and Sukhdev presented a slightly different picture of how the food system connects to the SDGs (Fig. 3.2)[3]. According to them, economies and societies have to be seen as embedded parts of the biosphere, rather than constituting three pillars of similar weight. Rockström and Sukhdev also point to the synergies of certain SDGs; for example, eradicating poverty (SDG 1) and hunger (SDG 2) requires gender equality (SDG 5), decent jobs (SDG 8) and reduced inequality (SDG 10). Rockström and Sukhdev do not present any specific indicators for measuring the sustainability of food systems

[3] http://www.stockholmresilience.org/research/research-news/2016-06-14-how-food-connects-all-the-sdgs.html

or diets. However, the 17 SDGs provide 169 targets and 304 indicators, some of which are applicable to sustainable diets and food systems.

Fig. 3.2. How food connects all the United Nations Sustainable Development Goals (SDGs). Rockström and Sukhdev (2016) presented a new way of viewing the SDGs and how they are all linked to food.

3.2 Sustainability assessment tools

To work towards greater sustainability, and particularly sustainable diets, ways to concretise sustainability and ways of measuring it are needed. The concepts ‘metrics’, ‘measures’ and ‘indicators’ are used differently in different contexts and are commonly used interchangeably. According to the Oxford English dictionary, a *metric* is used to define “*a system or standard of measurement*”; a *measure* is a value of something related to a standard, e.g. a weight in kilograms; and an *indicator* is related to some specific context, e.g. as defined by OECD/DAC (2010):

“A quantitative or qualitative factor or variable that provides a simple and reliable means to measure achievement, to reflect changes connected to an intervention, or to help assess the performance of a development actor”.

Indicators are important tools for enabling data to be handled in a consistent, comprehensive and understandable way. Indicators are commonly aggregated into composite indices (Fig. C2 in Appendix C). It is important to remember that indicators are not objective measurements, but rather context-laden socially constructed values (Mineur, 2007). When choosing indicators or when developing new indicators and indices, a range of different criteria should be considered, such as indicators being sensitive to change, possible to verify, objective, easy to use, policy relevant, comparable, understandable and so on. Appendix C provides more information on indicator selection and development, a full research field of its own. *“The Handbook on Constructing Composite Indicators”* includes valuable guidelines on the development of composite indicators (OECD and EC, 2008).

An alternative to aggregating indicators into one or only a few indices is to show results for many indicators (commonly aggregated into ‘themes’) on a common scale, using e.g. a spider diagram (Fig. 3.3). This is a common approach for evaluating farm-level sustainability (Schader et al., 2014; Marchand et al., 2014; Rasmussen et al., 2017). Such tools are sometimes termed integrated indicator-based sustainability assessment frameworks and typically include guidance on how indicators should be normalised, weighted and aggregated and how results of the assessment should be presented.

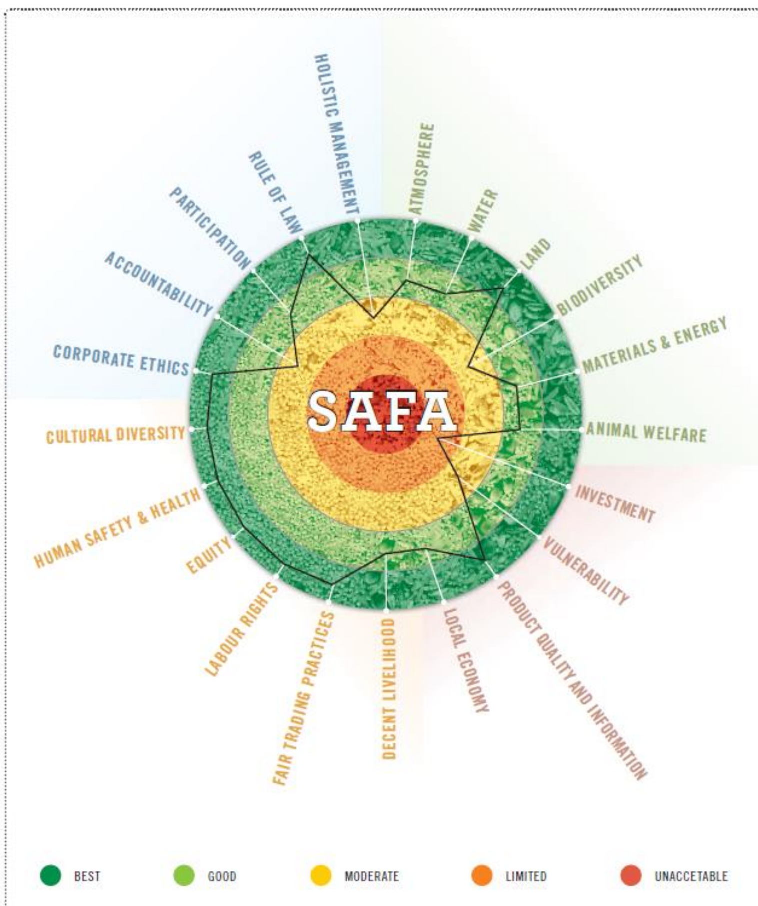


Fig. 3.3. Example of the structure (above) and results (left) of an integrated indicator-based sustainability assessment framework for farms and agribusinesses. The tool, called SAFA, was developed by the FAO and includes four dimensions of sustainability: good governance, environmental integrity, economic resilience and social well-being (FAO, 2014). Under these, there are 21 high-level sustainability themes applicable to all areas of sustainable development. Under these in turn, there are 58 sub-themes that specifically target agriculture and food. A number of indicators for each sub-theme are suggested. The SAFA guidelines further specify how indicators can be contextualised and how they should be rated, weighted and aggregated.

Another commonly used tool for estimating the environmental impact of products or services is life cycle assessment (LCA), which is a well-established quantitative and standardised method (ISO, 2006a, 2006b) structured into four stages (Fig. 3.4). In an LCA, resources used (e.g. raw materials, energy, land and water) and outputs created (products, by-products, emissions and waste) are quantified for all steps in the life cycle, starting at raw material extraction and continuing through to manufacturing, use and finally ending with disposal of the product. Resource use and emissions are aggregated across life cycle stages and related to one unit of the product or service under study, the so-called functional unit. Emissions of substances that cause the same type of environmental impact are characterised according to their ability to cause the impact in relation to a 'base' substance. For example, gases causing global warming are typically aggregated based on their ability to heat the atmosphere in comparison with carbon dioxide (CO_2) over a set time period. A common method is to determine global warming potential (GWP), which measures how much heat is trapped in the atmosphere by a certain gas over a period of time relative to the amount of heat trapped by CO_2 (Myhre et al., 2013). An LCA study typically contains many impact categories (e.g. eutrophication, toxicity, acidification, ozone). However, due to the interest in climate change and since emissions of GHG have the same impacts regardless of where they take place, it has become common to limit LCA to emissions of GHG, in which case the undertaking is called a product carbon footprint (PCF) and is defined in its own standard (ISO 14067).

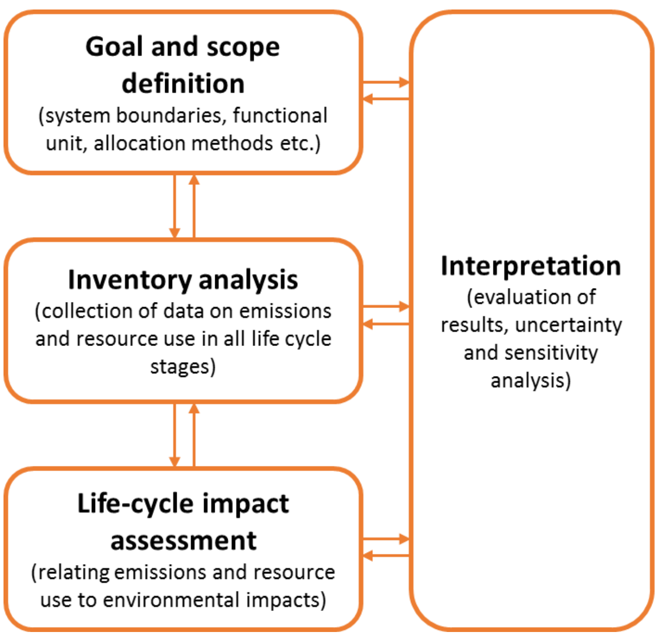


Fig. 3.4. The four phases of life cycle assessment.

To date, LCA has been limited to environmental impacts, but efforts have also been made to develop a method for undertaking social LCA (S-LCA) as well as life cycle costing (LCC) studies i.e. which also include social and economic perspectives. However, these are applied to a much lesser extent.

LCA is inherently a measurement of environmental ‘efficiency’ as it measures emissions and resource use per unit of produce (although impacts could also be assessed per area e.g. per hectare). As such LCA does not in itself provide any ‘sustainability thresholds’ (see section 4.6) as the total impact depends on the total usage of a specific product. That is, even though a product might have a low impact per kg of product compared to other products or services providing the same function, if the use of this product is high, the total impact will be high.

LCA can be applied to a multitude of products and used for answering a wide range of questions. Therefore the ISO-standard (ISO, 2006a; 2006b) is limited to providing some overarching guidelines and LCAs can be performed in many different ways. To increase comparability across studies, the methodology has been further standardised in standards targeting specific products. The ENVIFOOD Protocol for instance provides guidance on how to perform an LCA on food in general (FOOD SCP RT, 2013), while the International Dairy Federation (IDF) provides guidelines on how to calculate the carbon (IDF, 2010) and water footprint (IDF, 2017) of dairy products more specifically.

In addition to indicators, indices, sustainability assessment frameworks and LCA there are also other tools aimed at sustainability assessments. For an overview, see for example Gasparatos et al. (2008).

3.3 Health indicators at individual level

WHO defined health as early as 1948 as: "*a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity"*. This definition has been criticized for having too much 'breath and ambition', but it still serves as a good point of reference for what we should strive for. More concretely, health is often estimated in terms of disease outcomes, like such as mortality rate and morbidity prevalence. However, metrics for estimating the 'healthfulness' of a population or person based on self-rated health measurements also exist (DeSalvo et al., 2005). Since the experience of health or ill-health is ultimately subjective, this approach of rating one's experience of health is well suited in some cases. However, this approach also carries significant methodological problems and is perhaps less helpful when defining and designing sustainable and healthy diets, although for evaluation purposes it could play a role. Personal perception of health relies not only on one's physical condition but is also affected by many other factors, including how one perceives the healthiness of the food consumed and the wellbeing (emotional and social) one derives from the eating experience. Guyonnet et al. (2008) developed a questionnaire designed to measure the perceived impact and effects of the daily diet on several psychological parameters.

Mortality, as the name implies, describes a condition whose outcome is fatal, i.e. the death rate in a population. Morbidity, on the other hand, is the rate of disease in a population. Morbidity is often considered a relevant indicator of health and of the same magnitude as mortality, due to the suffering, societal and economic cost that morbidity causes. Morbidity can be measured in two ways, as prevalence and incidence. Prevalence is the total number of people with any given disease or condition at any given point in time, while incidence is the new number of cases within a specific time frame (i.e. one year). Prevalence is usually reported as the fraction or absolute number. Incidence is usually reported as an incidence rate within the population at risk, i.e. 2800 cases per 100,000 or 0.028%, for a specific time frame, i.e. one year (Willett, 2012).

There are several different health indicators available, with some having more depth and breadth and others being more specific. The Institute for Health Metrics and Evaluation (IHME), which together with several other organisations publishes the Global Burden of Disease study, uses the following indicators to evaluate health (IHME, 2013):

- Mortality
- Years of Life Lost (YLL) - years of life lost due to premature mortality
- Years Lived with Disability (YLD) - years of life lived with any short-term or long-term health loss
- Disability-Adjusted Life Years (DALY) - the sum of years lost due to premature death (YLL) and years lived with disability (YLD)
- Healthy Life Expectancy, or Health-Adjusted Life Expectancy (HALE) - the number of years that a person at a given age can expect to live in good health, taking into account mortality and disability.

In nutritional epidemiology, apart from mortality measurements, one common indicator is body mass index (BMI), an individual's weight divided by the square of their height, although other indicators also exist (Gibson, 2005). WHO has produced a comprehensive report on core health indicators (WHO, 2018).

Indicators such as BMI, DALY and the prevalence and incidence of certain diseases (e.g. lung cancer) are considered to be indicators with relatively high relevance in clinical applications. For example, if smoking is shown to increase the risk of lung cancer, this outcome warrants clear policies or recommendations. However, access to data for these kinds of indicators varies and epidemiological research therefore often uses indicators of less relevance (similarly to midpoints in LCA, see Appendix C3). These kinds of indicators are often markers of a potential disease or disease progression, and are less expensive and more readily available, which makes their use relatively common. Examples include blood level markers for cholesterol, blood glucose, hormone levels or mechanical indicators like blood pressure. Naturally, these indicators may not always affect the life quality of the patient and do not always lead to the diseases or outcomes associated with the indicators.

3.4 Health indicators at food and diet level

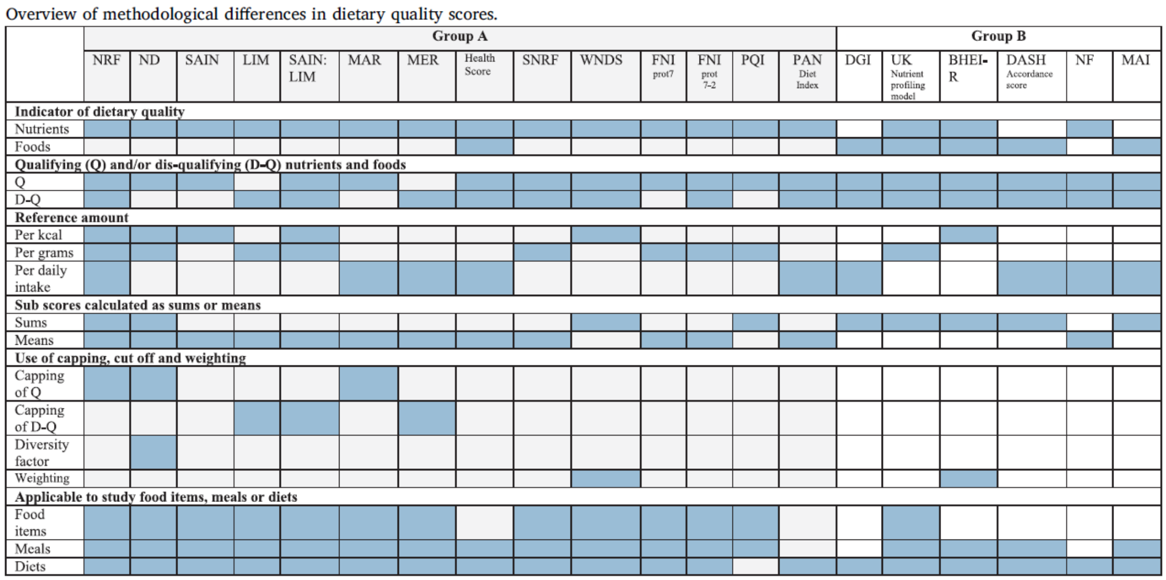
When measuring the 'healthfulness' of individual food items, nutrient profiling, i.e. categorisation of foods based on their nutrient content, is the main method (WHO, 2011b). A common approach in nutrient profiling is to use nutrient adequacy/density scores. Based on the nutrient content in foods or diets, several indices have been developed to determine the overall quality of foods and diets (Drewnowski, 2009; Arsenault et al., 2012; Drewnowski and Fulgoni, 2014). However, ranking foods based on their nutritional quality includes both conceptual and technical challenges and many design decisions are required, e.g. on which nutrients to include, the basis of calculations (grams, kcal or serving size), the choice of reference daily values, whether the nutrients should be capped at 100% of recommended daily allowance of nutrients or not, and which algorithm to use when calculating the actual index (WHO, 2011b; Hallström et al., 2018). In addition, whether nutrient indices are designed to be used on a specific category of foods or across all foods is another question. Therefore, results in terms of nutrient quality of foods or diets using nutrient profiling are highly dependent on the design of the profiling method. Examples of established nutrient profiling methods are the Swedish Keyhole[4], the European Nutriscore[5] and the Australian Five Star[6].

Nutrient adequacy/density scores can also be used to measure the healthfulness of diets**.** Vieux et al. (2013) used nutrient adequacy scores to rank individual diets according to their nutritional quality. They used the mean adequacy ratio (MAR), mean excess ratio (MER) and dietary energy density (DED) to rank diets into four different health categories. These were calculated for 20 nutrients, including protein and key vitamins and minerals, and three harmful nutrients (saturated fat, sodium and added sugars). MAR was calculated as the sum of all mean percentages of the daily recommended intake (DRI) for each key nutrient, with the ratio truncated at 100 so that high intake of some nutrients would not compensate for low intake of other nutrients. MER was calculated as the sum of intake of each detrimental nutrient divided by the maximum recommended value, with individual values below 100 truncated to 100 to avoid compensation from low values. DED is the total weight of the individual diet divided by the total caloric content (considering only items typically consumed as foods). Lower DED is expected to be beneficial to health in preventing obesity-associated diseases.

Another approach to measure the healthfulness of diets is to evaluate the quality of diets in terms of their dietary components rather than their nutrient content, for example consumption of fruit, vegetables, sugary drinks etc. The Healthy Eating Index (HEI) is one example (Heller et al., 2013). This can often be combined with certain aspects of nutrient profiling, such as share of calories derived from sugar or saturated fat. Scoring systems for dietary quality are often based on pre-existing nutritional guidelines or recommendations, but may also be derived from specific dietary patterns, such as the Mediterranean Diet Score (Waijers et al., 2007).

[4] https://www.livsmedelsverket.se/en/food-and-content/labelling/nyckelhalet
[5] http://www.euro.who.int/en/countries/france/news/news/2017/03/france-becomes-one-of-the-first-countries-in-region-to-recommend-colour-coded-front-of-pack-nutrition-labelling-system
[6] http://healthstarrating.gov.au/internet/healthstarrating/publishing.nsf/content/home

Hallström et al. (2018) reviewed the literature on dietary quality scores for assessing the sustainability of food and human diets and provide an overview of methodological choices for 20 different dietary quality scores (Fig. 3.5).



NRF = Nutrient Rich Food, ND = Nutrient Density Score, SAIN = Score for the nutritional adequacy of individual foods, LIM = Score for dis-qualifying nutrients, MAR = Mean Adequacy Ratio, MER = Mean Excess Ratio, SNRF = Sustainable Nutrient Rich Food, WNDS = Weighted Nutrient Density Score, FNI_{prot} = Finnish Nutrient Index for protein sources, PQI = Protein Quality Index, PAN Diet Index = Probability of Adequate Nutrient Diet Index, DGI = Dietary Guideline Index, UK Nutrient Profiling Model = United Kingdom Nutrient Profiling Model, BHEI-R = Brazilian Healthy Eating Index Revised, DASH Accordance Score = Dietary Approaches to Stop Hypertension Accordance Score, NF = Nutritional Footprint, MAI = Mediterranean Adequacy Index.

Fig. 3.5. Overview of nutrient quality scores used in the literature to assess the sustainability of foods and diets. From Hallström et al. (2018). (Note that the LIM and SAIN:LIM scores do not have 'capping of D-Q' and that MAR and MER are not applicable to food items.)

4. Sustainable diets

4.1 Definitions of sustainable diets

One of the most commonly cited definitions of sustainable diets is the following, from the book "*Sustainable Diets and Biodiversity - Directions and Solutions for Policy, Research and Action*" (FAO and BI, 2010):

"Sustainable diets are those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources."

This book was the result of an International Scientific Symposium "Biodiversity and Sustainable Diets: United Against Hunger" organised jointly by the FAO and Biodiversity International (BI). It was held at FAO headquarters in Rome in 2010, within the World Food Day/Week programme, during the International Year of Biodiversity. The definition stated above is sometimes referred to as the 'FAO definition' of sustainable diets.

Table 4.1 gives examples of other definitions of sustainable diets from different organisations and projects. Most organisations acknowledge the multifaceted aspects of sustainability, including social, economic and environmental aspects. In summary, all definitions explicitly state that sustainable diets should be healthy and protective of the environment. Almost all also include explicit statements on economic aspects, food safety and cultural acceptance. Two definitions raise the issue of animal welfare, one includes the feasibility of diets ("is practically feasible in everyday life") and one the aspect of good quality food ("improve people's experiences of good quality food"). Only one of the definitions (sustain org) does not mention explicitly the human health-promoting dimension of sustainable diets.

Table 4.1. Definitions of sustainable diets found in the literature through an iterative search on generic search engines

Organisation/author	Definition
FAO and BI (2010). Sustainable diets and biodiversity. Directions and solutions for policy, research and action.	"Sustainable diets are those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources."
Reisch LA (2010). A definition of "sustainable food consumption": Copenhagen Business School.	"For food consumption to be sustainable it has to be safe and healthy in amount and quality; and it has to be realized through means that are economically, socially, culturally and environmentally sustainable – minimizing waste and pollution and not jeopardizing the needs of others."
Sustain (2013). The Sustain guide to good food: How to help make our food and farming system fit for the future.	"Provide social benefits, such as safe and nutritious products, and improve people's experiences of good quality food, for instance by growing and cooking it, which helps to enrich our knowledge and skills, and our cultural diversity. Contribute to thriving local economies that create good jobs and secure livelihoods – both in the UK and, in the case of imported products, in producer countries. Enhance the health and variety of both plants and animals (and the welfare of farmed and wild creatures), protect natural resources such as water and soil, and help to tackle climate change."
The German Project Ernährungswende, lead author Doris Hayn. (Reisch, 2010)	Food consumption is defined to be sustainable only if it: ● is environmentally sound (water, soil, climate, biodiversity, avoidance of unnecessary risks); ● is health promoting; ● allows for socio-cultural diversity; ● is practically feasible in everyday life.
British Sustainable Development Commission (Reisch, 2010)	The commission considers food and drink sustainable if it: ● is safe, healthy and nutritious, for consumers in shops, restaurants, schools, hospitals etc.; ● can meet the needs of the less well-off people; ● provides a viable livelihood for farmers, processors and retailers, whose employees enjoy a safe and hygienic working environment whether nationally or abroad; ● respects biophysical and environmental limits in its production and processing, while reducing energy consumption and improving the wider environment; ● respects the highest standards of animal health and welfare, compatible with the production of affordable food for all sectors of society; ● supports rural economies and the diversity of rural culture, in particular through an emphasis on local products that keep food miles to a minimum.

4.2 Frameworks for sustainable diets

To our knowledge, there is no commonly used generic, operationalised broad framework for assessing the sustainability of diets, as there is for assessing the sustainability of farms (Fig. 3.3; Section 3.2). However, some reports and papers provide conceptual frameworks or indicators for a specific context, which are exemplified in this section.

Lukas et al. (2016) provides a framework for assessing the sustainability of meals which could also be applied to diets. The framework includes a set of environmental (carbon, material footprints, land and water use) and health indicators (intake of energy, sodium, dietary fibre and saturated fat), threshold levels (further discussed in section 4.6), a way to aggregate the results into one composite index (the Nutritional Footprint) and a ranking system ('low', 'medium' and 'high' effect). The framework was applied by Lukas et al. (2016) to eight meals and the results presented as the aggregated nutritional footprint (Table 4.2), and also in a diagram which shows the impacts for each indicator (Fig. 4.1).

Table 4.2. 'Nutritional footprint' of meals. From Lukas et al. (2016)

Menu	Nutritional footprint [(subtotal health + subtotal env.)/2)]	Nutritional footprint	Ranking
Menu 1 – Spaghetti bolognese with a small salad	[(2.25 + 2.25)/2]	2.25	High
Menu 2 – Classic curry sausage with chips and mayonnaise	[(2.75 + 1.75)/2]	2.25	High
Menu 3 – Beef roll with potatoes and vegetable in red wine sauce	[(2 + 3)/2]	**2.5**	High
Menu 4 – Large mixed salad with a baguette	[(1.25 + 1)/2]	1.125	Low
Menu 5 – Breaded sea fish fillet with remoulade sauce, potato and broccoli	[(2.25 + 1.25)/2]	1.75	Medium
Menu 6 – Veggie, zucchini, spinach and feta lasagne	[(1.5 + 1)/2]	1.25	Low
Menu 7 – Vegan – Chili sin carne	[(1.25 + 1)/2]	1.125	Low
Menu 8 – Potato pancake	[(2 + 1)/2]	1.5	Low

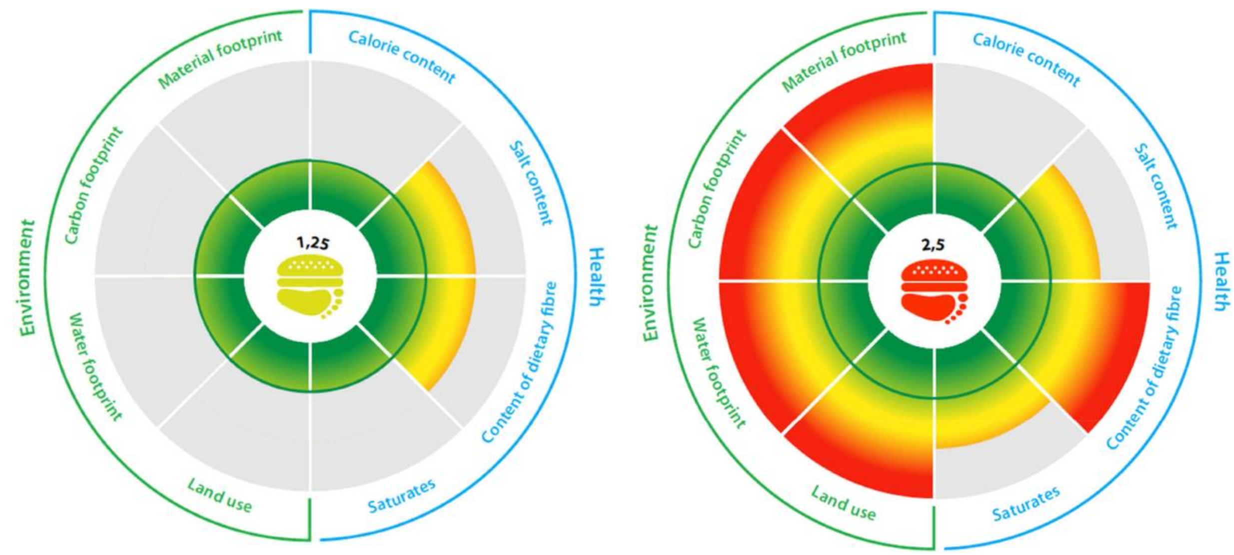


Fig. 4.1. Nutritional footprint of a veggie lasagne (left) and a beef roll menu (right). From Lukas et al. (2016).

The framework of Lukas et al. (2016) could potentially be useful for communicating the joint environmental and health impacts from different meals to e.g. consumers. However, the usefulness of the tool in this application has not been investigated, a point which those authors also highlight.

In their framework, the healthfulness of a meal is evaluated based on its energy, salt, fibre and saturated fat content, which is only a limited set of all the nutrients that are relevant for nutritionally adequate diets. Potentially, choosing these four is a valid simplification in the case of consumer communication that provides appropriate boundary conditions for a healthy meal; ensuring adequate energy intake while limiting salt and saturated fat and ensuring enough dietary fibre would steer the consumer towards meals rich in whole grains, roots and vegetables. However, inadequate protein intake could potentially be an issue and the same is true for certain micronutrients. The appropriateness of using these four health indicators would need to be tested on a larger set of meals and diets. An additional point that the authors highlight is that this framework has been developed for use in a high-income setting and might need adapting to suit another contexts. As regards environmental indicators, the framework lacks consideration of e.g. use of pesticides and impacts on biodiversity. In addition, as the authors highlight, there is some overlap between indicators. For example, the use of materials will show up in both the carbon footprint and the material footprint.

The Lukas et al. (2016) study illustrates several challenges in developing frameworks for sustainable diets, including the difficulty in choosing a limited and still appropriate set of indicators, how to aggregate and weight these (further discussed in section 4.5) and how to define thresholds and rating systems, i.e. what is considered high or low, green or red (see section 4.6). Inevitably, the design of a framework for sustainable diets includes a range of normative decisions that will influence the results. In addition, for such assessments to be useful for different types of decision making, they need to be perceived as understandable and relevant for involved stakeholders, which means that tools have to be tailored to different users and contexts. For example, a public agency, a researcher or an industry sustainability manager can handle greater complexity than can (most) consumers.

Heller et al. (2013) provide an interesting conceptual framework that views the damage to human health of a particular diet as a combined effect of the damage caused by the environmental impact and the direct effect of consuming a particular diet (Fig. 4.2). To our knowledge, this framework has never been applied quantitatively.

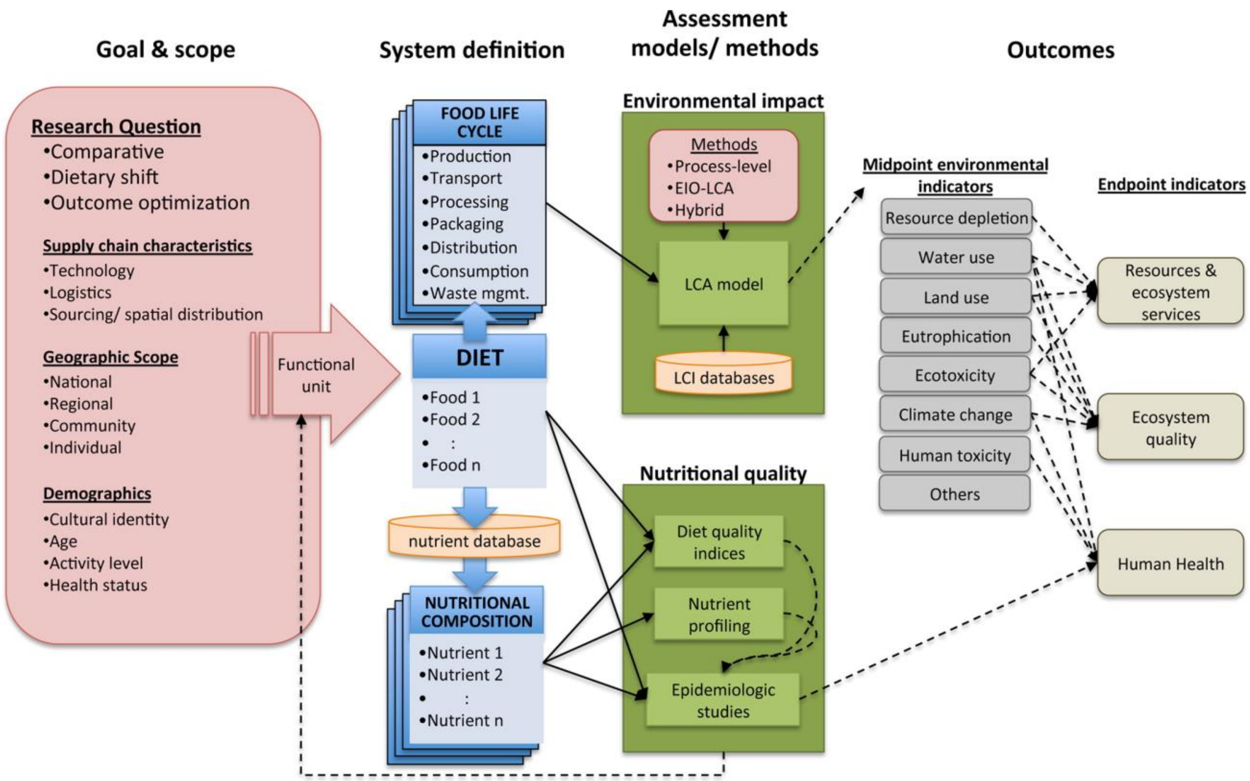


Fig. 4.2. Conceptual framework for diet-level integration of environmental impact and nutritional quality assessments. Reprinted with permission from (Heller MC, Keoleian GA, Willett WC. Toward a Life Cycle-Based, Diet-level Framework for Food Environmental Impact and Nutritional Quality Assessment: A Critical Review. Environmental Science & Technology. 2013 Nov 19;47(22):12632–47). Copyright 2018 American Chemical Society.

Gazan et al. (2018a) present a method for compiling food metrics related to diet sustainability relevant for a specific context. They illustrate their methodology using France as a case study, starting with the selection of diet sustainability dimensions and diet-related indicators, based to a large extent on data availability (Table 4.3). Data to calculate the metrics were taken from national and international standard nutrient composition tables and databases, surveys and scientific literature and stored in a common database. The metrics were then applied to 212 generic French foods. Compilation of these data enables assessment of diets, including health, cultural, economic and environmental perspectives. However, as the authors acknowledge, the choice of indicators is largely driven by data availability. For example, for environmental indicators, water use is missing.

Table 4.3. Sustainability dimensions, indicators and metrics used in Gazan et al. (2018)

Sustainability dimension	**Diet-related indicator**	**Food metrics**
Nutritional adequacy (sub-domain of the health dimension)	Diet quality	• Energy and nutrient contents • Content of other substances (e.g. phytate) • Bio-conversion factors (protein digestibility factor, pro-vitamin A carotenoid conversion factors) • Proportion of ingredients of animal/vegetable origin
Food safety (sub-domain of the health dimension)	Toxicological exposure	• Contaminant content
Cultural acceptability	Dietary pattern	• Distribution of dietary intakes in the population • Portion sizes
Economic affordability	Diet cost	• Prices
Environmental friendliness	Diet-related environmental impact	• Greenhouse gas emission • Water eutrophication • Air acidification

One of the more comprehensive compilations of issues related to sustainable diets is that by Garnett (2014), in which a sustainable diet is described by five core components: 1) society and ethics, 2) economy and food supply, 3) environment, 4) nutrition and 5) other food-related health (Fig. 4.3). Garnett (2014) describes how different food groups relate to the issues listed and discusses this in relation to the value-laden social context of sustainable diets, but does not provide any concrete metrics to quantitatively assess different diets.

Fig. 4.3. Issues to consider when defining a sustainable diet. From Garnett (2014).

Building on the work by FAO and BI, Johnston et al. (2014) present key components, determinants, factors and processes of sustainable diets (Fig. 4.4). They also highlight the need to develop indicators for measuring the different aspects and discuss the difficulty with this, especially in low-income settings due to lack of data and other constraints.

Fig. 4.4. Components, determinants, factors and processes of a sustainable diet. From Johnston et al. (2014).

Donini et al. (2016) present what they call a 'consensus proposal' of nutrition and health indicators. These were developed within an informal international working group consisting of organisations from mainly Mediterranean countries that worked for four years to identify and choose relevant indicators. The starting point was the so-called traditional Mediterranean diet. Thirteen indicators in five areas were identified:

- Biochemical characteristics of food (Vegetable/animal protein consumption ratios; Average dietary energy adequacy; Dietary Energy Density Score; Nutrient density of diet)
- Food Quality (Fruit and vegetable consumption/intake; Dietary Diversity Score)
- Environment (Food biodiversity composition and consumption; Rate of local/regional foods and seasonality; Rate of eco-friendly food production and/or consumption)
- Lifestyle (Physical activity/physical inactivity prevalence; Adherence to the Mediterranean dietary pattern)
- Clinical Aspects (Diet-related morbidity/mortality statistics; Nutritional anthropometry).

For each of these, Donini et al. (2016) provide a definition, methodology, background, data sources, limitations of the indicator and references. For environmental indicators, these do not describe the actual performance in terms of contributing to different impact categories such as climate impact, water use, eutrophication etc. Instead, potential drivers of such impacts are used, based on the assumption that local/regional foods and organic foods provide environmental advantages. While this is true for some aspects, e.g. production of organic foods is associated with considerably lower use of pesticides than conventional production, it is not certain that local foods provide environmental benefits, as that depends on how production is carried out rather than where it is located. None of the environmental indicators suggested by Donini et al. (2016) would capture the greater environmental impacts generally caused by diets high in animal products.

Another approach to evaluate the sustainability of diets is through coupled agriculture and health modelling, in which economic models are used to predict food consumption and their influence on production and the resulting environmental impacts. For example, Springmann et al. (2017) used such an approach including a global risk-assessment framework with five disease states and six dietary and weight-related risk factors to predict health outcomes from dietary changes induced by placing a tax globally on food in relation to the food's climate impact.

Downs et al. (2017) present a framework for policy analysis for sustainable diets. It contains a comprehensive set of issues (compiled from among others Garnett (2014)) related to sustainable diets structured into five domains (1) nutrition and health; (2) agriculture and food security; (3) environment and ecosystems; (4) markets, trade and value chains for economic growth; and (5) sociocultural and political factors. Downs et al. (2017) use the framework to examine three Nepalese food-related policies by evaluating whether and to what extent these policies address the different sustainability issues in the framework.

4.3 Frameworks for sustainable food systems

Although the focus of the present report is on sustainable diets, below we present some recent examples of multicriteria frameworks evaluating sustainable food systems, as some metrics and approaches included in these might also be applicable to diets.

Gustafson et al. (2016) propose a framework based on the concept of 'sustainable nutrition security' (SNS) and consisting of seven different metrics (Fig. 4.5). Within each metric, there are several indicators that are combined into a single score for each metric. The results can then be visualised using a spider diagram and serve as a foundation for comparing SNS between different countries.

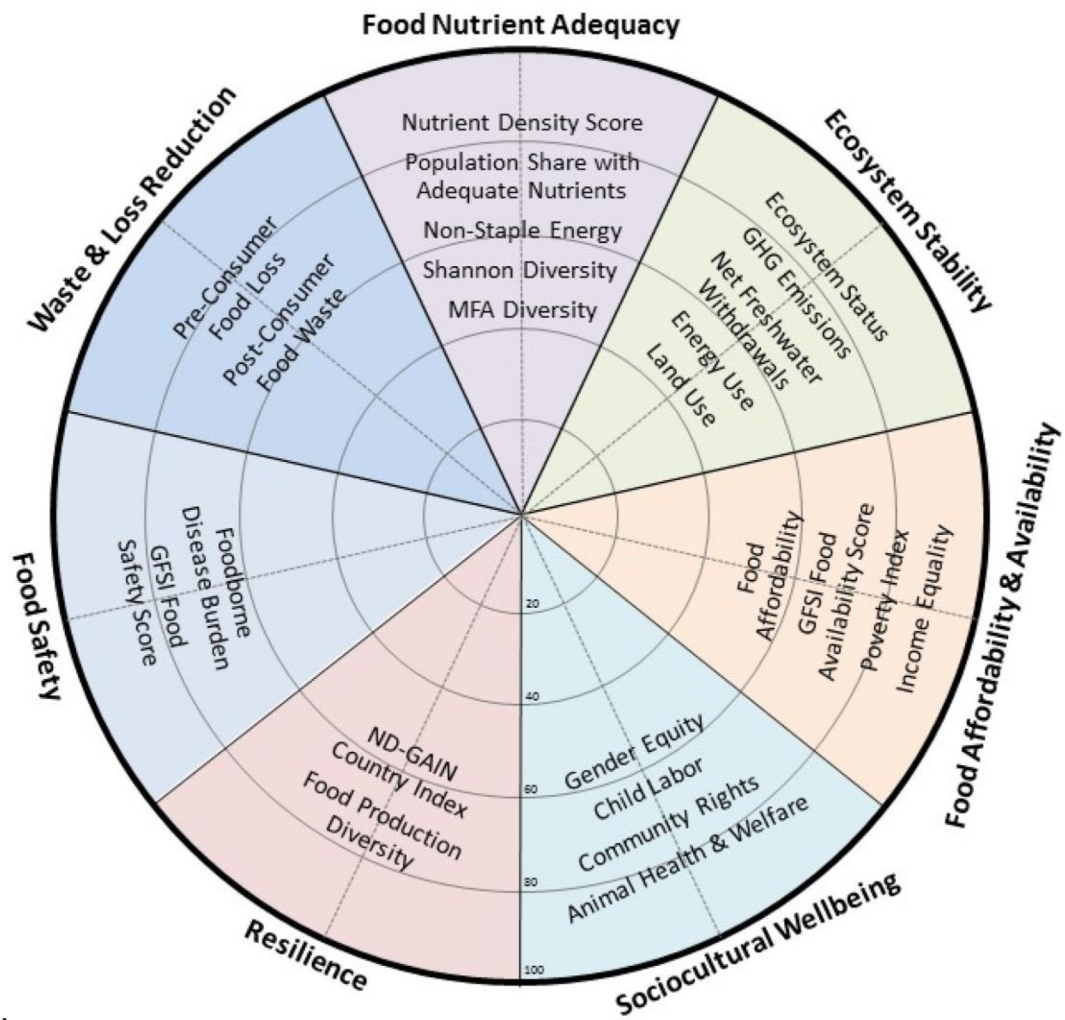


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Fig. 4.5. Schematic diagram of the framework presented by Gustafson et al. (2016), incorporating seven metrics for sustainable food systems.

Chaudhary et al. (2018) applied the SNS framework with some modifications to three alternative dietary alternatives (healthy global diets, lacto-ovo vegetarian and vegan) in 156 countries, using the framework to assess differences in food system sustainability depending on different diets.

For the Food Nutrient Adequacy metric, two additional indicators were used, the Nutrient Balance Score (NBS), i.e. the daily average intake amounts of 25 essential (qualifying) nutrients compared with their Reference Daily Intake values, and the Disqualifying Nutrient Score (DNS), i.e. the total daily intake of four nutrients to limit (sugar, cholesterol, saturated fat and total fat) with their Maximal Reference Values. These two replaced the Nutrient Density Score used in Gustafson et al. (2016). Hence, stronger weight was given to the nutrients to limit, which decreased the positive bias toward high-income countries. To the Ecosystem Stability metric was added the Biodiversity Footprint, which uses the methodology in Chaudhary and Kastner (2016) to account for land use biodiversity impacts associated with international trade.

For comparison between diets, Chaudhary et al. (2018) show results explicitly for the NBS, the DNS, the PAN (Population Share with Adequate Nutrients) and the carbon and water footprints for different regions and countries. To give an example, results for Europe and Central Asia are shown in Table 4.4.

Table 4.4. Impact from different diets on five sustainability indicators for two world regions. From Chaudhary et al. (2018)

Region	**Scenario**	**Nutrient Balance Score, NBS**[1]	**Disqualifying Nutrient Score, DNS**[1]	**Population Share with Adequate Nutrients, PAN**[1]	**Carbon footprint** (kg CO_2e per capita)	**Water footprint** (L per capita)
Europe and Central Asia	Reference	80	10	82	3.04	303
	Healthy diet[2]	+1	+3	-4	-0.89	-68
	Lacto-ovo vegetarian[3]	0	+10	-5	-1.48	-79
	Vegan[4]	-4	+50	-12	-2.01	-85
Sub-Saharan Africa	Reference	71	38	68	1.48	141
	Healthy diet	+3	-1	+9	+0.24	+35
	Lacto-ovo vegetarian	+1	+3	+5	-0.25	+33
	Vegan	0	+13	+3	-0.37	+34

[1]Scaled from 0 to 100, a NBS or DNS value of 100 means perfectly nutritious diet. A PAN score of 100 implies that 100% of the region's population is meeting daily nutritional requirements.
[2]The scenario assumes that people consume just enough calories to maintain a healthy body weight and that food intake complies with dietary guidelines on healthy eating. The four constraints included for constructing a diet (per day) were: less than 50 g of sugar and 43 g of red meat, a minimum of five portions (400 g) of fruit and vegetables and 2200-2300 kcal of total energy intake (depending on the age and sex composition of the population)
[3]The five constraints applied in this diet scenario (per day) were: less than 50 g of sugar, no red meat, poultry or fish, 2300 kcal of total energy intake, at least six portions of fruit and vegetables (6 × 80 g), and at least one serving (80g) of legumes/pulses. There was no constraint or allowable level defined for eggs/dairy intake in this scenario and it was treated in the same way as other food items such as wheat or rice.
[4]The constraints in the vegan diet scenario were the same as in the vegetarian diet scenario, except a minimum of seven portions of fruit and vegetables per day (7×80g) instead of six and also no eggs or dairy.

The Barilla Center for Food and Nutrition (BCFN) provides another example of a method for assessing food system sustainability and for ranking countries, namely the sustainability index (FSI) (BCFN, 2017). The index includes three pillars; 1) food loss and waste, 2) sustainable agriculture and 3) nutritional challenges, and is a qualitative and quantitative benchmarking model that permits country-to-country comparisons. The index consists of 35 indicators and over 55 sub-indicators. The results for a large number of countries and description of the methodologies are available on a website[7]. BCFN provides free and full access to all data and models, which makes it possible for anyone to use the data and results.

These two very comprehensive tools provide interesting information on an aggregated national level about food system sustainability. However, comprehensiveness inevitably brings complexity, making it difficult to grasp the practical relevance of a higher or lower score when so many factors are taken into consideration. A more detailed analysis of the results and how they are derived is needed to enable wise decisions based on these tools. The aggregation level may hide country specific trade-offs such as the importance of grazing animals for biodiversity in some regions. Consideration of nutrient status on aggregated level hides nutritional challenges for different groups such as children, women and the elderly. However, these frameworks and their indicators could be valuable with some modification for studying specific issues in specific contexts. Depending on the research question, the stakeholders involved and the budget of the project, a subset of relevant indicators from these frameworks can then be selected.

For more information on initiatives for measuring the sustainability of food systems, Prosperi et al. (2015) provide a good overview. Furthermore, Heller and Keoleian (2003) suggest a set of indicators associated with different stages in the food supply chain.

[7] http://foodsustainability.eiu.com/heat-map/

4.4 Studies measuring specific aspects of sustainable diets

The number of studies looking at a limited set of aspects related to the sustainability of diets has increased substantially during the past decade. Auestad and Fugoni (2015) provide a review of papers on sustainable diets across academic disciplines (agriculture, nutrition and health, animal science, environmental sciences, social sciences, economics and policy) published up to April 2014. Only studies that examined impacts of dietary patterns on at least one indicator of environmental sustainability were included. The most recent systematic review on sustainable diets is that by Jones et al. (2016), where lack of metrics and shared approaches in the assessment of sustainable diets served as the rationale for the study. Jones et al. (2016) identified 30 'components' of sustainable diets (Table 4.5) from 113 studies in total. They applied a systematic search method covering 30 databases in the fields of nutrition, public health, agriculture, ecology, economics, social science, public policy and environmental and climate change. They also examined references of identified articles, prominent policy reports, previous literature reviews and archives of selected indexed journals.

To complement the study by Jones et al. (2016) with later research findings, when preparing this report we conducted an additional search for 2016 and 2017 in 27 databases (through Pubmed/Medline), using the same search phrases and exclusion criteria as applied by Jones et al. (2016). Our additional results can be seen together with the results from Jones et al. (2016) in Table 4.5 (the full list of references and the exclusion criteria used by Jones et al. (2016) are provided in Appendix D). In addition to the components in Table 4.5, we identified additional components that were not identified in the review by Jones et al. (2016). These were:

- Material footprint
- Dietary diversity score
- Physical inactivity/activity prevalence
- Adherence to the Mediterranean dietary pattern/Mediterranean diet index
- Nutritional anthropometry
- Resilience
- Socio-cultural wellbeing
- Food safety
- Food affordability and availability
- Employment
- Metabolic food waste
- Metabolic energy density
- Nutrient-scaled carbon footprint.

Table 4.5. Components of sustainable diets identified by Jones et al. (2016) and in an updated search in February 2018 covering the years 2016 and 2017

Component:	**No. of studies in Jones et al. (2016) in which it is included:**	**Number of additional studies 2016-2017 in which it is included:**
Greenhouse gas emissions	71	20
Land use	32	11
Consumption of meat and dairy	30	2
Diet quality	27	10
Energy use	26	4
Management practices/organic food	21	1
Water use	20	9
Local or seasonal food procurement	18	1
Cost of diets and revenue generation	13	2
Eutrophication potential	11	3
Health	11	2
Reactive nitrogen	9	1
Acidification potential	8	2
Human toxicity/ecotoxicity	8	1
Social equity	8	1
Food waste	7	1
Ozone layer depletion	6	0
Ecology/environment	5	0
Animal welfare	5	0
Fisheries	3	0
Community	2	0
Policy	2	0
Phosphorus use	2	1
Bottled water consumption	2	0
Food packaging	2	0
Biodiversity	2	2
Cultural appropriateness	2	2
Abiotic resource use	1	1
Mineral extraction	1	0
Landscape character	1	0

Jones et al. (2016) concluded that, although they found 30 distinct components of sustainable diets, "*neither the distribution nor complexity of components identified in existing conceptual frameworks of sustainable diets is evident in the empirical research that has measured sustainable diets*".

A comparison of the comprehensive framework presented by Garnett (2014) and the list of components compiled by Jones et al. (2016) shows that there are gaps between Garnett's framework and current research investigating sustainable diets. Although several of these components could be accounted for implicitly, there is no explicit inclusion of e.g. agriculture-linked infectious diseases (zoonotic, vector-borne), occupational injuries and taste in current literature. Moreover, consideration of soil fertility and health seems to be completely absent.

A limitation with the Jones et al. (2016) review is that the ‘components’ presented include indicators used to assess diets, such as carbon footprint and water use, and other characteristics of potentially more sustainable diets that were investigated in the studies reviewed, but not always measured, e.g. management practices/organic food and local and seasonal food. ‘Consumption of meat and dairy’ was a component found in 30 of the studies reviewed, but it did not appear to have been actually used as an indicator in any of the studies. Instead, studies were considered to include this component if e.g. they compared diets with different amounts of meat. However, ‘amount of animal protein’ could be an interesting, albeit coarse, indicator to use for sustainable diets, as it drives several other environmental aspects and is one important factor for nutrition. For a more detailed description of some common indicators found in the Jones et al. (2016) review, see Appendix E. In addition, a recent literature review by van Dooren et al. (2018) (which included the Jones et al. review) intended “*to identify a set of crucial indicators to assess the most pressing environmental impacts of diets*” provides a good overview of potential indicators for diet sustainability. They conclude that emissions of GHG and land use address most of the environmental impact of diets well, but that these indicators should be supplemented with indicators addressing nitrogen and phosphorous efficiency.

In summary, most current literature on healthy and sustainable diets commonly only includes one or a few issues when assessing the sustainability of diets, hence potentially failing to capture both important synergies and goal conflicts. This is understandable considering the complexity of assessing impacts from a large range of foods for many issues. Lack of data is also a major limitation. However, several studies indicate that in general, GHG emissions and land use are reasonable proxies for some other, but not necessarily all, environmental pressures (see e.g. Röös et al., 2013; van Dooren et al., 2018).

4.5 Methods for indicator weighting and diet optimisation

Inherently, multi-dimensional assessments of foods and diets give a multitude of results for different indicators. These results can be presented separately, enabling e.g. the study of trade-offs and the identification of especially problematic areas. Indicators can also be aggregated to one or a few indices (section 3.2). In the latter case, the question arises of how indicator results can be weighted. As assessments of diets often show trade-offs, one might want to optimise the diet to reach the most optimal result in term of several indicators. This section provides some information on the issues of weighting and diet optimisation.

Computerised dietary programming (CDP) is one way to optimise diets with regard to several indicators and has been used to create new, more sustainable dietary recommendations and guidelines (e.g. Gazan et al., 2018b). In CDP, mathematical optimisation of diets is performed using linear or quadratic programming. Software programs handle data on several different variables, such as macro- and micronutrients, GHG emissions and land use, and optimise diets based on minimising e.g. GHG emissions while meeting nutrient recommendations or keeping diets as similar as possible to a reference diet (commonly the current diet) while GHG emissions are reduced. In the EU project SUSDIET (ended in 2017), CDP (a tool developed by MS Nutrition in France) was used to develop nutritionally adequate diets with low GHG emissions that deviate as little as possible from current dietary patterns achieved within the EU. Some results from this project were recently published in a study by Vieux et al. (2018). In that study, nutritionally adequate diets for each gender were developed using optimisation techniques starting from average observed diets (gender-specific) in five European countries (France, UK, Italy, Finland and Sweden) and applying stepwise 10% reductions in GHG emissions. Results from that study are presented and discussed in section 5.2.2 of this report.

The WWF UK report "*Eating for 2 Degrees – New and Updated Livewell Plates*"[8] describes another project that used CDP (the Optimeal® program from Blond Consultants). The Netherlands Nutrition Centre also used CDP to develop their new 'Wheel of Five' tool, which gives examples of healthy dietary patterns (Brink et al., 2017). An example of an ongoing research project using CDP is Optimat in Sweden[9], which aims at optimising Swedish school meals. The project includes a modelling study to develop food baskets optimised for low emissions of GHG, adequate nutrient composition, good acceptability and low cost.

CDP is a powerful tool for identifying optimal dietary outcomes considering a set of constraints. However, it can be difficult to handle a large set of constraints and setting constraints is of course to some extent normative. All aspects included need to be documented in a quantitative manner, which might lead to diets that deviate widely from current eating patterns and are hence unrealistic, although this can be overcome by including criteria on e.g. how much the diet may deviate from current diets. Interlinkages within food production (e.g. dairy milk is accompanied by a certain amount of ruminant meat) may be difficult to consider, as these are

[8] https://www.wwf.org.uk/eatingfor2degrees

[9] http://ki.se/en/phs/community-nutrition-and-physical-activity

8http://ms-nutrition.com/

highly relevant on an aggregated population level but less so on an individual level, so are commonly not accounted for. However, the study by Barré et al. (2018) included links between milk-beef and blood sausages-pork in optimisation of diets, by constraining their respective quantities proportionally.

There are several methods available for weighting different aspects or indicators and these can be conceptually divided into monetary and non-monetary value-based methods. Monetary methods include measuring the willingness-to-pay (WTP) for certain aspects (e.g. biodiversity conservation, limiting GHG emissions etc.) among different stakeholders (Ahlroth et al., 2011). Non-monetary weighting methods include 'distance-to-target' and panel weighting models. Distance-to-target models assume that all targets or endpoints are of equal importance and therefore should be prioritised in accordance with how far a threshold is exceeded or the current state of a given environmental dimension or system. In panel weighting models, participants' values are investigated through questionnaires or interviews where the respondents are asked to rank the importance of different aspects. Depending on the purpose of the investigation and the topic investigated, panels can have differing composition, although the most common participants are experts, stakeholders or the general public.

In a paper by Tuomisto et al. (2012), a distance-to-target approach was implemented with the Planetary Boundaries as a proposed framework and applied on five different farming systems[10]. Depending on how far the Planetary Boundaries were trespassed, the systems received different weights. For example, as addition of nitrogen (at the time of writing the paper) was 121 millions of tonnes per year and the Planetary Boundary is defined as maximum 35 million tonnes per year, the weight applied to 'the nitrogen cycle' was 121/35=3.46, and so on for the other Planetary Boundaries (Table 4.6). However, this method has been criticised on the basis that it is not possible to 'trade' one Planetary Boundary for another, as they must be considered absolute limits. However, this criticism is not unique to the distance-to-target method and applies to all weighting methods, as these deal with the aggregation and prioritisation of different impacts.

Table 4.6. Weighting factors for different environmental aspects proposed by Tuomisto et al. (2012).

Planetary Boundary	Weighting factor
Climate change	1.31 (0.86-1.76)
Biodiversity loss	10 (1-10)
Nitrogen cycle	3.46
Phosphorus cycle	0.82 (0.08-0.86)
Ozone depletion	1.02
Ocean acidification	1.05
Global freshwater use	0.65 (0.43-0.65)
Land use	0.78

[10]Goossens et al. (2016) further suggest how LCA midpoint indicators can be mapped against the Planetary Boundaries.

In the framework developed by Gustafson et al. (2016) for sustainable food systems (see section 4.3), every metric is symmetrically weighed within each of the seven dimensions, which is a common approach.

A novel approach for creating weighting factors was presented by Ji and Hong (2016). Through the use of Google Trends©, which is an open-access browser software for analysing search term popularity, they managed to compile weighting factors based on search terms relating to global warming, ozone depletion, resource depletion, photochemical oxidation, eutrophication and acidification. Since search terms are country-specific, weighting factors for three different countries are presented by Ji and Hong (2016).

For further reading on weighting factors from the field of LCA, see e.g. Soares et al., (2006), Agarski et al. (2016), Pizzol et al. (2015), Ahlroth (2014) and Ahlroth et al. (2011). For an example of a food-related study that used methods from the field of multi-criteria decision analysis, see Linnemann et al. (2015).

4.6 Defining rating systems and thresholds for sustainable diets

If indicator results are to be presented on some type of scale (e.g. in a spider diagram or rated as high-low, red-yellow-green etc.), a rating system needs to be established. This inevitably involves making normative decisions and, depending on how the results are to be used, different strategies make more or less sense. It is possible to differentiate between relative and absolute sustainability ratings. Relative rating systems compare the object under study (in this case the food item or the diet) with similar objects, e.g. whether the food item or diet performs better or worse than average, is among the top 10% performers etc. However, even a system, product or diet that is 'best in class' in a given situation may not be sustainable. To determine whether a system, product or diet is sustainable, there is a need to establish absolute sustainability thresholds, which is very difficult.

The Planetary Boundary concept developed by Rockström et al. (2009) and further refined in Steffen et al. (2015) is one of the most commonly referenced concept of thresholds for environmental impact (Appendix A). It defines quantified Planetary Boundaries for climate change, change in biosphere integrity, stratospheric ozone depletion, ocean acidification, biochemical flows, land-system change, freshwater use, atmospheric aerosol loading and introduction of novel entities. These boundaries are defined on a global scale and for impacts from all sectors. Therefore they do not give any guidance on how much of the impact in a specific category can come from the food system or the diet of a person. However, such food system-specific boundaries are being developed by the EAT Lancet Commission and are to be published in the beginning of 2019[11]. Some studies have also broken down the Planetary Boundaries in order to apply them to diets or agricultural systems. As an example, the boundaries used by Röös et al. (2016a) for absolute sustainability in a study of Swedish diets based on the 'livestock in leftovers' approach (section 4.7) are shown in Table 4.7.

[11] https://foodplanethealth.org/the-report/

Table 4.7. Boundaries used for 'absolute sustainability". From Röös et al. (2016a)

	Planetary Boundary	**Boundary used for the diet in this study**
Climate change	CO_2 concentration of maximum 350 ppm	Since this boundary has been exceeded, production of the diet should not give any net emissions
Biosphere integrity	10 extinctions per million species-years	All current semi-natural grassland and arable land in Sweden preserved (these are the most threatened eco-systems in Sweden)
Nitrogen cycle	62 Tg of N added per year from industrial and intentional biological N fixation	6.5 kg N per capita added per year to produce the diet (the boundary divided by the global population in 2050)
Phosphorus cycle	Maximum of 6.2 Tg mined P applied to agricultural soils	0.65 kg P added per capita per year to produce the diet (the boundary divided by the global population in 2050)
Land system change	Max 15% of the global land surface should be converted to arable	Production of the diet uses maximum 0.21 ha arable land per person (the boundary divided by the global population in 2050)

Quite a few studies have tried to define thresholds for climate change and land use. For example, when quantifying GHG emissions, land use and biodiversity impacts for three Swedish diets[12], Röös et al. (2015a) used a boundary for GHG emissions of 750 kg CO_2e per person and year, based on emissions pathways to meet the 2-degree temperature goal and a boundary for land use of 0.32 ha per person per year based on agricultural land availability in Sweden. By doing so, they were able to show the environmental impact of the diets on the same scale as the nutritional content, which was normalised based on recommended intakes (Fig. 4.6).

[12]The three diets were: SNÖ - a diet corresponding to Nordic recommendations as defined by the Swedish National Food Agency reflecting food preferences in Sweden; Riksmaten - the current average Swedish diet according to the latest food intake survey; LCHF (Low-Carb, High-Fat) - a lifestyle diet widely used in Sweden. All diets were adjusted to the same total energy intake level, 10.1 MJ/person/day.

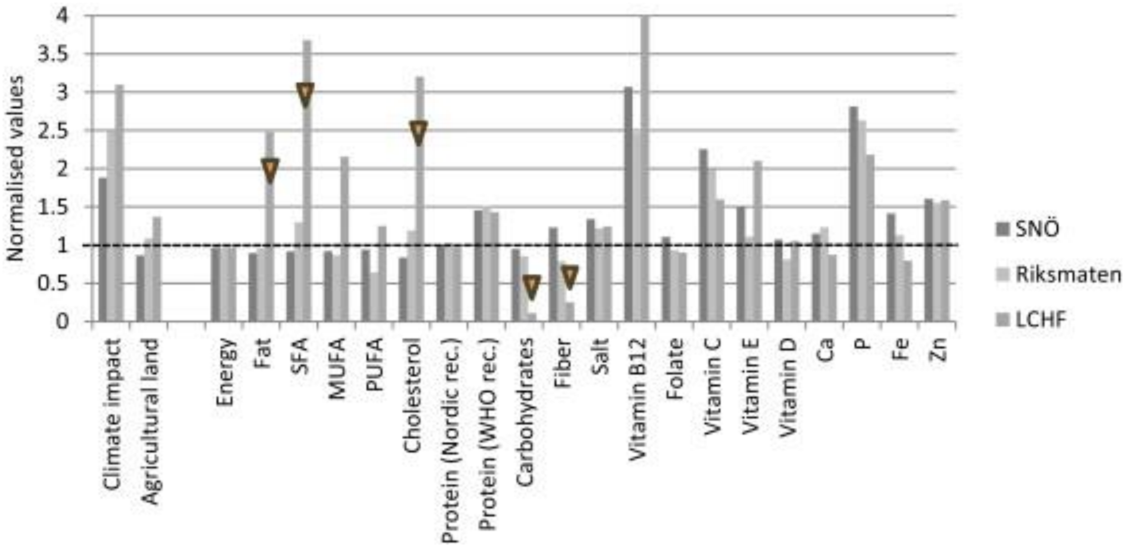

Fig. 4.6. Climate impact, agricultural land occupation and nutrient intake for three different Swedish diets (SNÖ =recommended diet, Riksmaten = current diet, LCHF = low-carb, high-fat diet). The y-axis shows the normalised values, where 1 corresponds to the per capita 'sustainable level' of climate impact and agricultural land occupation as defined in the study. For nutrients, 1 on the y-axis corresponds to the recommended intake according to the Nordic Nutrition Recommendations. From Röös et al. (2015a).

Another example is the WWF UK's *Livewell Plate* project, which used the UK government's commitment to reduce territorial GHG emissions by 61% by 2030 to develop a threshold for food consumption. It was assumed that half the reduction will be achieved through improvements in production and the other half through dietary changes, giving a daily per capita threshold of 4.09 kg CO_2e (1.5 tonnes per year) for food in 2030. The Livewell Plate project also established thresholds for use of cropland and grassland and several dietary and nutritional constraints regarding macro- and micronutrients and food groups (fish, red and processed meat, oily fish, fruit and vegetables, beverages). Interestingly, in their One Planet Plate concept[13], WWF Sweden go considerably further, setting the threshold at 11 kg CO_2e per week (590 kg CO_2e per year) based on the 1.5 degree climate target and not accounting for technological advances. Greenpeace's newly launched food vision aims at limiting emissions from agriculture to 4 Gt CO_2e per year in 2050, corresponding to approximately 400 kg CO_2e per person and year (Greenpeace, 2018). This variation in thresholds illustrates how value-laden definitions of thresholds are (further discussed in section 4.9).

Lukas et al. (2016) (see section 4.2) define three relative threshold levels for environmental indicators and nutritional indicators based on nutritional recommendations and literature data (Table 4.8).

[13]http://www.wwf.se/press/pressrum/pressmeddelanden/1734329-idag-lanserar-wwf-planetsakra-maltider-one-planet-plate-och-matkalkylatorn.

Table 4.8. Basic estimates of threshold levels for environmental indicators. From Lukas et al. (2016)

	Proposal for threshold level (per capita & day)		
Indicator	**Strong impact**	**Medium impact**	**Low impact**
Material footprint	>12 kg	8-12 kg	<8 kg
Carbon footprint (CO_2e)	>3.6 kg	2.4-3.6 kg	<2.4 kg
Water footprint	>2925 litre	1950-2925 litre	<1950 litre
Land use	>5.625 m^2	3.75-5.625 m^2	<3.75 m^2
Calorie intake	>2500 kcal	2000-2500 kcal	<2000 kcal
Sodium	>10 g	6-10 g	<6 g
Dietary fibre	<18 g	18-24 g	>24 g
Saturated fat	>30 g	20-30 g	<20 g

As regards social boundaries, Kate Raworth's 'doughnut economics'[14] provides a framework for combining the Planetary Boundaries with those of human prosperity, hence providing a 'social foundation' of what is needed for human well-being and an 'ecological ceiling' which has to be respected for safe Earth system functioning (Fig. 4.7). The social foundation is not limited to diets, nutrition and health, but also includes aspects such as housing and education. It could be an interesting exercise to try to establish a social foundation for diets specifically in terms of 'good enough' nutrition including nutrient intakes, variety of foods, cultural acceptance etc.

[14] https://www.kateraworth.com/.

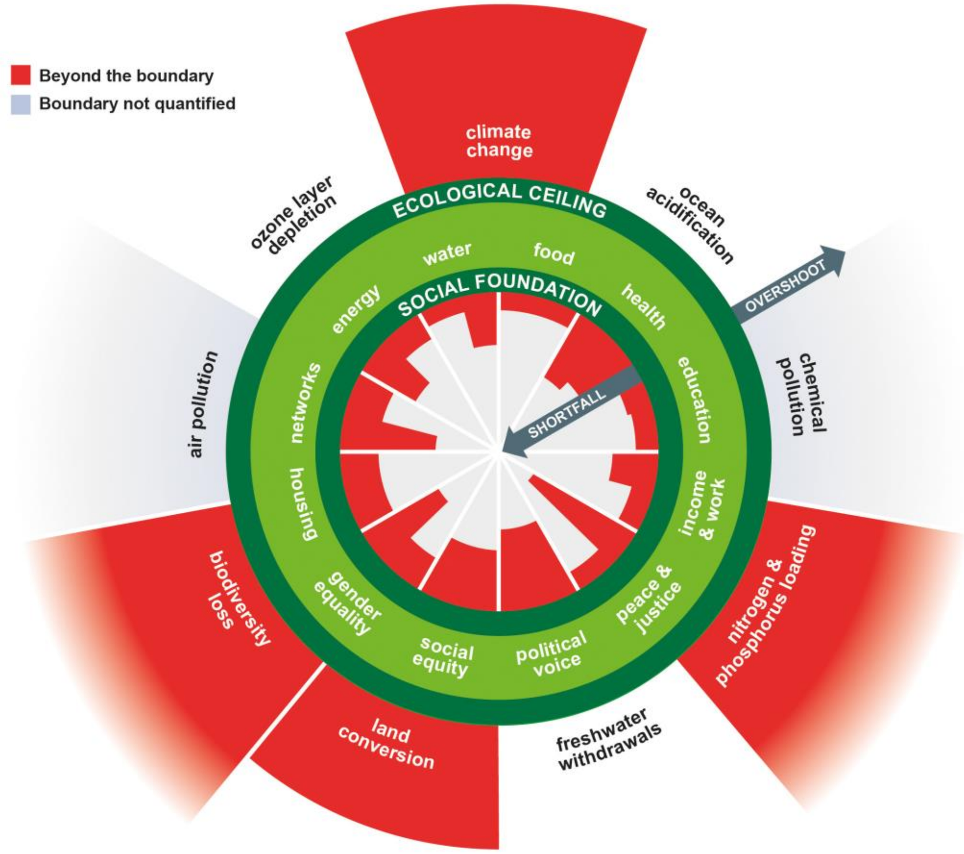

Fig. 4.7. The doughnut concept developed by Raworth (2012) for defining social and environmental boundaries for human prosperity.

O'Neill et al. (2018) used this framework to investigate whether countries are currently meeting these thresholds. They found that no country is currently meeting basic needs for its citizens without also transgressing environmental boundaries. They also concluded that basic needs such as nutrition, sanitation, access to electricity and the elimination of extreme poverty for all could likely be met within Planetary Boundaries, but that high life satisfaction would require a level of resource use that is 2-6 times the sustainable level.

4.7 A 'livestock-on-leftovers' approach to sustainable diets

When assessing the sustainability of diets, the starting point is commonly a specific, actual or theoretical diet in some situation, e.g. the current diet in a specific country or region, the Mediterranean diet, a potential or optimised low meat, vegetarian or vegan diet etc. Commonly, no consideration is given to the capacity to produce this diet.

An alternative approach for designing diets is to start by considering the available land resources that can be used to produce as much food as possible for the least negative environmental impact and what kind of diet that would give. In such an approach, livestock production is limited to resources that are not digestible or not wanted by humans, e.g. biomass from land unsuited for crop production, by-products from crop production and food waste. Several studies based on this concept, called e.g. 'default livestock' or 'livestock on leftovers', have been published and are summarised in Table 4.9. On average, a daily per capita amount of animal protein of approximately 21 g could be supplied to all in 2050 while limiting livestock production to such non-food-competing feed resources (van Zanten et al., 2018). This 21 g corresponds to e.g. approximately 100 g of raw bone-free meat, or 50 g of meat and 300 mL milk (or some such combination). It should be noted, however, that much of the animal protein comes from feeding pigs food waste, a practice which is currently not permitted in the EU. To supply adequate nutrition (recommended daily protein intake is around 0.8 g/kg of body weight adult), the omitted animal products in these diets are replaced by cereals, legumes (ensuring requirements on protein quality are met) and vegetable oil.

The 'livestock-on-leftovers' approach provides a land boundary condition for livestock production (van Zanten et al., 2018). As long as livestock eat human-edible feedstock they do not contribute to food security, as most of the energy and proteins are lost in the metabolic process of the animal. However, if they eat non-food biomass, they recycle nutrients back into the food system and contribute positively. Hence, one could argue that livestock should be limited to the number needed to consume these 'leftover' streams.

However, a food system based on the 'livestock-on-leftover' approach would look radically different from current systems. For example, poultry production would decrease by over 90%, while ruminant numbers would not be reduced as drastically as they are able to digest cellulose-rich biomass, most importantly grass. Although a food system based entirely on the 'livestock-on-leftover' approach is far from implementation and current trends are moving in the opposite direction, it might be useful to include indicators for assessing sustainable diets that account for food-feed competition, e.g. kg human-edible protein fed to livestock per kg protein in the diet.

Table 4.9. Description and findings in studies based on the 'livestock on leftovers' concept. From Garnett et al. (2017)

Study	Feedsources used	Human diet modelled	Assumptions about waste	Animal productivity	Total animal protein, g/ person/day
Schader *et al.* (2015)	Pastures (3.38 Gha – utilisation rates derived from current feeding rations and animal numbers) Currently available by-product shares (oil-cake, brans, whey, etc.) applied to projected production volumes.	Projected average food energy intakes for 2050.	No food waste fed.	2050 forecasts by Alexandratos and Bruinsma 2012 – global average.	11 g of which 4 g is milk (cattle, sheep, goat, buffaloes), 1 g is non-ruminant meat (poultry and pigs), 3 g is ruminant meat (cattle, buffaloes, sheep and goats), 2 g is fish. Protein from eggs is negligible.
Van Zanten *et al.* (2016)	Pastures (3.34 Gha), 10% of food waste produced, co-products from a vegan diet.	A mainly vegan healthy diet with added animal products producible from associated waste streams, co-products and grazing lands.	Co-products available based on global consumption of a healthy largely 'default' vegan diet (i.e. co-product availability limited to what can be derived from this dietary pattern). Waste levels are assumed to be 10% all food produced (i.e. down from current levels); all food waste and co-products fed to pigs, ruminants 100% grassfed.	Global average for 2050.	21 (of which 7 g is milk and ruminant meat and 14 g is pork).
Röös *et al.* (2017)	Pastures (3.36 Gha – 30% forage offtake rate), food waste and co-products (fishmeal, oil cake, fibre-rich by-products) from seafood and plant-based foods in the projected diet in 2050 and food waste.	Business as usual projected diets.	Current waste levels continue as today. 30% cereals in pig diets to ensure nutritionally adequate pig diets; co-products to both pigs and ruminants. By-products and co-products available based on current global projected diets.	Swedish high end productivity for all livestock	32 (of which 9 g is milk, 9 g is ruminant meat and 14 g is pork).
Röös *et al.* (2017) – second scenario of above	Pastures (3.36 Gha – 30% forage offtake rate), food waste and coproducts (fishmeal, oil cake, fibre-rich by-products) from seafood and plant-based foods in the projected diet in 2050 and food waste.	Business as usual projected diets.	Waste reduced by 50%, 30% cereals in pig diets, co-products to both pigs and ruminants. By-products available based on a projected diet.	Swedish high end productivity for all livestock.	26 (of which 9 g is milk, 10 g is ruminant meat and 6 g is pork).

4.8 Dietary guidelines and sustainability

Dietary guidelines are important tools in guiding towards and informing about sustainable food choices. The most common approach to dietary guidelines is Food-Based Dietary Guidelines (FBDG), often targeted towards the healthy population as a whole. FBDG are commonly based on outcomes in terms of nutritional research, current consumption patterns and the health and nutritional status in a given population. The guidelines are hence tailored to suit how people are currently eating, rather than giving recommendations on the 'optimal' diet. FBDG are used to encourage healthier diets that are likely to be accepted and adopted by the majority of the population. To date, most FBDG are based on nutritional considerations only, but some progressive countries have incorporated environmental considerations into the guidelines. Gonzalez-Fischer and Garnett (2016) provide a review of such dietary guidelines, identifying three different types:

- Official guidelines. These guidelines are formal and represent the country's ambition to promote sustainable eating habits at population level.
- Quasi-official guidelines. These guidelines combine health and sustainability messaging and stem from government agencies or government-funded entities.
- Non-official guidelines. These are guidelines presented by NGOs, academic bodies or corporations and reflect the views expressed by these entities.

At the time of writing their review, Gonzalez-Fischer and Garnett (2016) found that Sweden, Brazil, Germany and Qatar in varying ways had national sustainable dietary advice that explicitly aims to lead consumers to make more sustainable food choices. Quasi-official guidelines distributed in Germany, the Netherlands, Estonia, the UK, France and Sweden, and also non-official FBDG that include aspects of sustainability, are summarised in Appendix F. There have also been attempts at creating sustainable FBDG in the US and Australia, but due to industry intervention they have been unsuccessful (Gonzalez-Fischer and Garnett, 2016). Since Gonzalez-Fischer's and Garnett's (2016) review, Belgium has also published new recommendations that include sustainability messages (FIHL, 2017). The Dutch guidelines were updated in 2016 to include environmental aspects; their new 'Wheel of Five' includes e.g. maximum limits for animal products (Brink et al., 2017).

Below is an excerpt from the executive summary by Gonzalez-Fischer and Garnett (2016) on the main findings of their review:

"*All the countries who do provide guidance on sustainability say broadly similar things despite differences in emphasis and level of detail provided (Table 1). All highlight that a largely plant-based diet has advantages for health and for the environment. Sweden is notable in additionally providing more detailed advice on which plant based foods are to be preferred, recommending for example root vegetables over salad greens. Most guidelines that include sustainability talk about the high environmental impact of meat – with the exception of the Qatari guidelines – but the advice often lacks specificity, and where recommended maximum levels are given, these are in line with recommendations of solely health-oriented guidelines. The Brazilian guidelines are distinct in emphasising the social and economic* *aspects of sustainability, advising people to be wary of advertising, for example, and to avoid ultra-processed foods that are not only bad for health but are seen to undermine traditional food cultures. They stand in contrast to the largely environmental definition of sustainability adopted in the other guidelines. Fish is presented as the main area where health-environment trade-offs arise, but advice is nevertheless given to continue to consume in quantities consistent with health recommendations. Most guidelines that include sustainability mention milk and dairy products directly or indirectly but the nature of the advice is variable. Advice on food waste and energy efficient cooking is patchy and represent an area with scope for easy 'win wins.'*"

Regarding the environmental impact from following FBDG, a study by Behrens et al. (2017) assessed the environmental impact of national recommended diets (NRDs) in 37 countries. When stratifying NRDs for high, high-middle and low-middle income countries, they found that (on average, but with exceptions) following the NRDs from high and upper-middle income countries would mean a reduction in environmental impact compared with the current situation, while following the NRDs from low-middle income countries would mean an increase in environmental impact. The reduced environmental impact in high-income countries was driven by recommendations to decrease calories (approx. 54% of the effect) and changes in diet composition (approx. 46% of the effect). The increased environmental impact in low-middle income countries was associated with increased intake of animal products and increases in caloric intake in some cases.

In a study by Ritchie et al. (2018), the recommended diets of six countries (Canada, USA, Australia, China, Germany and India) were investigated. For India, two types of recommendations were included, a vegetarian and a non-vegetarian recommendation. The distinction between these was that the dietary guidelines by default recommend pulses as the main protein source, but for non-vegetarians an option of replacing one portion of pulses with one portion of meat, fish or eggs is presented[15]. The recommendations were evaluated based on their GHG emissions, not including post-farm emissions and emissions from land use change. The carbon footprint of the recommended diets was found to vary between 687 and 1579 kg CO_2e per capita per year (Ritchie et al., 2018). Most of the variation was due to differences in recommendations for dairy intake. Fig. 4.8 shows the carbon footprint of the recommended diets, together with the total per capita budgets for emissions from all sectors as defined in the study (see section 4.6 for variation in thresholds). All recommended diets exceeded the limit for the 1.5 degree climate target, except for India and the WHO diet. All diets stayed below the 2 degree target, but left little room for emissions from other sectors (e.g. energy, transport).

[15]The Indian diet consisted of 560 g of staples, 90 g of legumes, 300 g of dairy, 30 g of oils, 30 g of sugar and 400 g of fruit and vegetables.

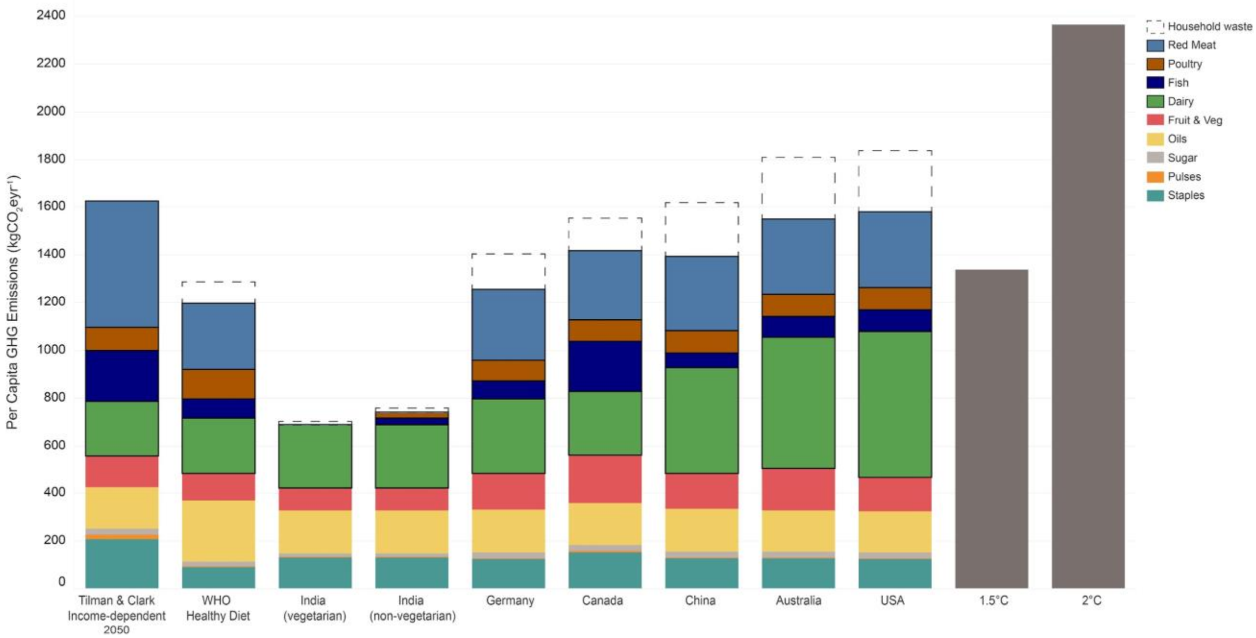

Fig. 4.8. Per capita greenhouse gas (GHG) emissions from diets based on World Health Organization (WHO) and national dietary guidelines. Dashed lines indicate the additional GHG emissions from food waste at household level. From Ritchie et al. (2018).

4.9 Norms, views and perspectives on sustainable diets

As the growing body of research and advocacy on sustainable diets makes clear, there is increasing recognition of the need for a shift towards diets that are 'better' than the status quo, across various dimensions. However, notwithstanding the many frameworks and indicators developed and under development, the multidimensional nature of sustainability makes it difficult to agree on what sustainability actually looks like 'on the plate'. This is partly for practical reasons, as some aspects of sustainability are more difficult to measure than others, but is also largely a matter of differing values and priorities.

For example, there can be very different views on how far current dietary and underpinning production practices can and should be changed, and how far technological advances will preclude the need for radical shifts. Many of these differences derive from disagreements on e.g. the importance of personal responsibility versus state action, the extent to which we should mitigate rather than adapt to the environmental problems we face, or how far certain desires (such as the desire for meat) are a socio-cultural construct, as opposed to a biological imperative.

Linked to this, there are different views as to what the 'boundary conditions' – the non negotiables – for defining sustainable diets should be. For many environmental NGOs and researchers, the boundary condition is that of environmental limits and the priority is to shrink our consumption patterns to fit the 'safe operating space' available for humanity (Rockström et al., 2009; Steffen et al., 2015; Appendix A). This points to a need for drastic changes in what we eat, and in particular to reduced consumption of animal products.

For other stakeholders, the circumscribing boundary conditions are the workings of the global economy, the inevitability of rising demand or the healthfulness of the human diet. While such stakeholders recognise that changes in consumption patterns may be possible at the margins and can be achieved through e.g. improved consumer awareness, fundamentally these groups rely on technological improvements to come up with solutions, such as product reformulations to improve the acceptability of healthier or more sustainable foods, the development of methane inhibitors in the rumen of cattle or the use of renewable energy sources to produce fertilisers or for processing.

These differences in perspective also manifest themselves in discussions about nutrition and good health. For example, many environmental campaigners tend to focus more on the problematic macronutrients (energy, fat) associated with excessive consumption than on the micronutrients (iron, zinc, calcium) associated with insufficiency, which may skew their attitudes to the role of meat in the diet. Others, such as nutritionists and members of the food industry, point to the nutrient density of animal products and warn that a reduction in their consumption could increase the risk of micronutrient deficiencies. These differing perspectives play out in their imaginings of what an alternative 'less meat/dairy' scenario might look like. From one perspective, should access to animal products be limited by (for instance) price, regulation or changing societal norms, this could be a positive development nutritionally. The assumption here is that less meat or dairy in the diet enables increases in consumption of legumes, nuts, fruit and vegetables. An alternative position might warn of negative consequences, however, since people will more likely switch to eating refined carbohydrates, high in sugar and possibly salt, with damaging health consequences.

There are also different perspectives on what constitutes ‘good enough’ nutrition, based on differing attitudes to risk and to the relative importance of human versus planetary needs. Some may accept a diet inadequate in certain micronutrients, arguing that these can be met through fortification strategies. They may also place more emphasis on minimum average nutritional requirements than on higher ‘safe’ levels – the different calcium recommendations given in different national dietary guidelines today provide a case in point. Others may take a more cautious attitude to risk that involves ‘safe’ higher level requirements for key nutrients or argue that human needs come before the environment. Attitudes to naturalness may also shape ideas as to the acceptability of fortification versus the consumption of foods naturally rich in certain nutrients.

In conclusion, ideas about sustainability are shaped by values as much as by science. People’s values shape which metrics are chosen and prioritised, and what options people believe to be possible or necessary.

5. The role of dairy and plant-based dairy alternatives in sustainable diets

Dairy products include milk, cheese, yogurt, butter and whey protein. Milk can come from any mammal, but dairy products used for human consumption are usually provided by (bovine) cattle, sheep, goats, horses, camels and buffalos, with cattle milk making up 83% of global production in 2016. Milk consumption varies greatly between regions and countries, with the global average being 90 kg per capita and year. Western Europe and North America consume around 250 kg per capita and year, whereas the average consumption in Africa is approximately 44 kg per capita and year (FAOSTAT, 2018).

Plant-based dairy alternatives include a wide range of products, including substitutes for milk, cheese and cream, yogurt-type products, desserts and spreads, and are made of soy, legumes, seeds, nuts or cereals. Some soy-based products (e.g. soy drink) have been used for a very long time, while other products (based on legumes, seeds, nuts and cereals) appeared on the market only in recent decades. Measured in terms of retail sales, the global dairy alternatives market was worth an estimated $16 billion in 2016, a 320% increase compared with 2006. The global milk market in considerably larger than the global milk alternatives market, but the gap has been closing quickly in the past decade. In 2006, the global milk market was 14.3 times larger than the dairy alternatives market, whereas in 2016 it was only 6.5 times larger (Wood, 2017).

In this section, we first very briefly summarise existing research on the health effects of dairy and plant-based dairy alternatives (section 5.1). We then move on to look at the environmental impacts of the two from different perspectives (section 5.2). Both fields are challenging due to their complexity, as is illustrated and discussed in this section.

5.1 Health effect of dairy and plant-based dairy alternatives

The ‘healthfulness’ of different foods can be evaluated in different ways, including:

- Evaluation of the nutrient content (e.g. energy, protein, vitamins etc.) and the nutritional density of the food
- Intervention studies, in which the intervention (e.g. consumption of a certain food) involves a group of study objects and outcomes are compared with those of a control group not subject to the intervention. Intervention studies are considered to provide the most reliable evidence in health research. The most relevant type of intervention study is the randomised controlled trial (RCT)
- Nutritional epidemiology, in which large amounts of data (e.g. on food intake and disease prevalence) are collected over extended periods and then used to investigate how consumption levels of certain foods correlate with disease risk. The most common type of study in nutritional epidemiology is the prospective cohort study, which follows large groups of people (the cohort) over long periods before diseases occur (prospective). Other types of studies exist, such as case-control studies and retrospective cohort studies.

As it is difficult to isolate the effect of eating a certain food on the outcome, individual intervention and epidemiological studies may show differing results. Therefore, to draw general conclusions on the health effect of certain foods from individual studies, the results are gathered into meta-analyses, which pool together the results and weight them according to the size of the study. In order for a meta-analysis to be of value, studies should be collected through a systematic search process.

5.1.1 Nutritional content

Data on the nutritional content of different food products are available in different internet-based databases commonly administered by national food agencies, such as the United States Department of Agriculture (USDA),[16] the Swedish National Food Agency[17],the French Food Safety Agency (ANSES)[18], the Dutch Food Composition Database (NEVO)[19] and Public Health England[20].

The aims of national food databases can slightly differ and therefore also their structure and content. For example, the main aim of the Swedish food composition database is to provide nutrient information on representative foods on the Swedish market, and hence to enable the food agency to calculate energy and nutrient intakes from diet surveys. Due to cost constraints, composite samples using similar products, but from different brands, are often analysed to get a representation of the 'average product' on the Swedish market (Öhrvik et al., 2015). The nutritional value of a product of a specific brand on the market may therefore differ from the nutritional value reported in the database for the composite sample of the product. The USDA database is slightly differently constructed, presenting data for a wide variety of brands for any given food product.

Table 5.1 shows an extract from the Swedish database for milk and unfortified and fortified soy, oat and almond drink and soy drink from the UK database. On the European market, over 90% of plant-based dairy alternatives are fortified (Stephanie de Vriese, Alpro, personal communication 2018). For comparison, Table 5.2 shows the nutrient content of corresponding products on the US market.

[16]Link: https://ndb.nal.usda.gov/ndb/search/list

[17]Link: http://www7.slv.se/SokNaringsinnehall/Home/ToggleLanguage

[18]Link: https://www.anses.fr/en/content/anses-ciqual-food-composition-table

[19]Link: https://nevo-online.rivm.nl/Default.aspx

[20]Link:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/416932/McCance___Widdowson_s_Composition_of_Foods_Integrated_Dataset.xlsx

Table 5.1. Nutritional content of dairy milk and plant-based dairy alternatives according to the Swedish food composition and the UK database. Values are given per 100 grams. N/A=Not analysed, Tr=Traces, RAE=Retinol activity equivalents.

	Milk			**Oat drink**		**Soy drink, Swedish d.b.**		**Soy drink, UK database**		**Almond drink**	
Nutrients	*Full fat*	*Semi-skim.*	*Low fat*	*Fortified*	*Un-fortified*	*Fortified*	*Un-fortified*	*Fortified* +	*Unfortified*Ψ	*Fortified*	*Unfortified*
Energy (kcal)	60	47	39	42	41	37	37	43	26	26	26
Carbohydrates (g)	4.7	4.8	4.8	7.1	7.6	3.2	3.2	2.5	0.5	3.5	3.5
Sugars (g)	4.8	4.9	4.9	3.2	4	2.4	2.4	2.2	0.2	3.1	3.1
Fat (g)	3	1.5	0.5	1.1	0.5	1.5	1.5	2.4	1.6	1.3	1.3
Saturated fat (g)	1.92	0.96	0.32	0.09	0.1	0.15	0.15	0.38	0.24	0	0.12
MUFA (g)	0.75	0.37	0.12	0.55	0.2	0.26	0.26	0.51	0.33	0.01	0.81
PUFA (g)	0.07	0.04	0.01	0.32	0.2	0.61	0.61	1.39	1.1	0	0.26
Cholesterol (mg)	10.3	6.1	3.3	0	0	0	0	0	0	0	0
Protein (g)	3.51	3.57	3.6	0.35	0.93	2.57	2.57	3.1	2.4	0	0
Fibre (g)	0	0	0	0.8	0.8	0	0	0.5	0.5	0.2	0.2
Calcium (mg)	120	122	124	120	5	96.5	19	130	13	133	133**
Magnesium (mg)	11	11	11	3.8	4	14.4	14.4	18	15	6.4	6.4
Iron (mg)	0.02	0.02	0.02	0.15	0.1	0.37	0.37	0.31	0.43	0.05	0.05
Phosphorus (mg)	102	104	105	26.2	20	89.7	89.7	89	48	67	67
Potassium (mg)	161	163	165	31.6	30	135	135	119	74	16.5	16.5
Sodium (mg)	39	40	40	40.3	40	37	37	56	32	49.4	49.4
Zinc (mg)	0.43	0.43	0.44	0.09	0.05	0.26	0.26	0.3	0.3	0.04	0.04
Vitamin C (mg)	0.6	0.6	0.6	0	0	0	0	0	0	0	0
Vitamin D (μg)	1	1	1*	1.62	0	0.74	0	0.8	0	0.93	0
Thiamine (mg)	0.05	0.05	0.05	0.03	0.03	0.03	0.03	0.06	0.06	0	0
Riboflavin (mg)	0.15	0.15	0.15	0.24	0	0.21	0.17	0.2	0.05	0.2	0
Niacin eq. (mg)	0.9	0.9	0.9	0.1	0.2	0.6	0.6	0.8	0.7	0.1	0.1
Vitamin B6 (mg)	0.04	0.05	0.05	0.13	0.13	0	0.03	0.03	0.03	0	0
Folate (μg)	14.3	14.6	14.7	17.9	0	16.1	16.1	9	14	0.4	0.4
Vitamin B12 (μg)	0.58	0.59	0.59	0.46	0	0.38	0	0.4	0	0.38	0
Vitamin A, RAE (μg)	27.7	13.8	4.6	36.3	0	0	0	Tr†	Tr†	0	0
Vitamin E (mg)	0.08	0.04	0.01	1.34	0	0.16	0.16	0.32	0.32	2.9	0
Iodide (μg)	11.8	12	12.1	0	0.1	0	0	1	1	0	N/A
Selenium (μg)	1.61	1.62	1.63	0	0	0	0	4	4	0	0

*Low fat milk is fortified with vitamin D in Sweden **This value cannot be correct through deductive reasoning, but is presented as this in the food composition database. †Traces of retinol equivalents. +Sweetened. ΨUnsweetened.

Table 5.2. Nutritional content of dairy milk and plant-based dairy alternatives according to the USDA food composition database[21]. Values are given per 100 grams. Zero values with exceptional detail (such as 0.0 to 0.000) are rounded off to zero (0). N/A=Not analysed, RAE=Retinol activity equivalents.

	Milk			**Soy milk**		**Almond milk, fortified**		**Coconut milk**	**Rice milk**
Nutrients	*Whole*[22]	*Red. fat*[23]	*Low fat*[24]	*Fortified*[25]	*Un-fortified*[26]	*Sweet-ened*[27]	*Unsweet-ened*[28]	*Fortified and sweetened*[29]	*Fortified and unsweetened*[30]
Energy (kcal)	61	50	42	28	54	38	15	31	47
Carbohydrates* (g)	4.78	4.8	4.99	4.14	6.28	6.59	1.31	2.92	9.17
Sugars (g)	5.05	5.06	5.2	3.65	3.99	6.25	0.81	2.5	5.28
Fat (g)	3.27	1.98	0.97	0.04	1.75	1.04	0.96	2.08	0.97
Saturated fat (g)	1.865	1.257	0.633	0	0.205	0	0.08	2.083	0
MUFA (g)	0.812	0.56	0.277	0	0.401	0.625	0.59	0	0.625
PUFA (g)	0.195	0.073	0.035	0.036	0.961	0.208	0.24	0	0.313
Cholesterol (mg)	10	8	5	0	0	0	0	0	0
Protein (g)	3.15	3.3	3.37	2.47	3.27	0.42	0.4	0.21	0.28
Fibre (g)	0	0	0	0.2	0.6	0.4	0.2	0	0.3
Calcium (mg)	113	120	125	116	25	188	184	188	118
Magnesium (mg)	10	11	11	10	25	7	6	0	11
Iron (mg)	0.03	0.02	0.03	0.35	0.64	0.3	0.28	0.3	0.2
Phosphorus (mg)	84	92	95	87	52	8	9	0	56
Potassium (mg)	132	140	150	105	118	50	67	19	27
Sodium (mg)	43	47	44	57	51	63	72	19	39
Zinc (mg)	0.37	0.48	0.42	0.1	0.12	0.63	0.06	0	0.13
Vitamin C (mg)	0	0.2	0	0	0	0	0	0	0
Vitamin D (µg)	0.1	1.2	1.2	1	0	1	1	1	1
Thiamine (mg)	0.046	0.039	0.02	0.022	0.06	0.015	0	0	0.027
Riboflavin (mg)	0.169	0.185	0.185	0.174	0.069	0.177	0.01	0	0.142
Niacin (mg)	0.089	0.092	0.093	0.323	0.513	0.075	0.07	0	0.39
Vitamin B6 (mg)	0.036	0.038	0.037	0.024	0.077	0.003	0	0	0.039
Folate (µg)	5	5	5	7	18	1	1	0	2
Vitamin B12 (µg)	0.45	0.53	0.47	0.23	0	1.25	0	1.25	0.63

[21]From the 'Standard reference' database. For cow's milk, milk types were chosen to match those types presented in Table 5.1. with regard to fat content and fortification. For plant-based dairy alternatives, flavoured drinks were avoided, with the exception of vanilla which is very common. When several types of products were available, the product with most types of nutrients analysed and displayed were chosen. Only one unfortified product was available. There is some difference in the types of vitamins presented in Table 5.2 compared with Table 5.1. The data from USDA present values for niacin, instead of niacin equivalents as in Table 5.1. Niacin equivalents is the sum of preformed niacin present in the food and the amount of niacin that can potentially be formed based on the amount of the amino acid tryptophan present in the food. 60 mg of tryptophan is equivalent to 1 mg of niacin equivalents.

[22]01211, Milk, whole, 3.25% milkfat, without added vitamin A and vitamin D.

[23]01079, Milk, reduced fat, fluid, 2% milk fat, with added vitamin A and vitamin D.

[24]01082, Milk, low fat, fluid, 1% milk fat, with added vitamin A and vitamin D.

[25]16230, Soy milk (all flavours), non-fat, with added calcium, vitamins A and D.

[26]16120, Soy milk, original and vanilla, unfortified.

[27]14016, Beverages, almond milk, sweetened, vanilla flavour, ready-to-drink.

[28]14091, Beverages, almond milk, unsweetened, shelf-stable.

[29]14171, Beverages, coconut milk, sweetened, fortified with calcium, vitamins A, B12, D2.

[30]14639, Beverages, rice milk, unsweetened.

Vitamin A, RAE (µg)	46	55	58	61	0	63	0	63	63
Vitamin E (mg)	0.07	0.03	0.01	0.08	0.11	2.81	6.33	0	0.47
Iodide** (µg)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Selenium (µg)	3.7	2.5	3.3	1.8	4.8	0.1	0.1	0	2.2

*Calculated by difference **Not analysed in the USDA's food composition database. Furthermore, iodide is not analysed by the USDA and therefore not presented in Table 5.2.

Energy

Plant-based drinks generally have a somewhat lower energy content than milk, but this depends on the fat content of the milk and on the type of plant-based drink that is compared. Although energy intake should be tailored according to an individual's metabolic need, food with lower energy density is usually recommended in high- and middle-income settings, as excess energy intake is generally a major problem.

Protein

Dairy milk contains approximately 3.4% protein[31], soy drink approximately 3% and other plant-based drinks less than 1%. Milk contains all essential amino acids, as does soy protein, although the amounts of different amino acids vary (Fig. 5.1). As different age groups have different amino acid requirements (EFSA, 2012), the most favourable product for any given individual will differ. Cereal-based proteins often have lower lysine content, whereas legume- based proteins often have lower contents of cysteine and methionine. Soy protein is an exception and is generally regarded as a complete protein for the adult population. Protein quality can be determined through various scoring systems, the most readily used and recognised being the Protein Digestibility-Corrected Amino Acid Score (PDCAAS), because it combines biological value (completeness) and digestibility. The PDCAAS score for milk, soy and wheat is 100 (121 if not truncated at 100), 91 and 42, respectively (Schaafsma, 2000).

[31]Proteins are made up of amino acids. There are 20 different amino acids commonly found in plants and animals. Amino acids can be classified as either essential (indispensable amino acids that cannot be produced during metabolism by the body and therefore must be provided by the diet) or non-essential (dispensable amino acids that can be produced endogenously in the body from other amino acids). Nine amino acids (histidine, leucine, isoleucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine) are considered essential for adults and these nine plus arginine for preterm infants. In addition, there are two semi-essential amino acids that can be metabolised in the body from essential amino acids: Cysteine is made from methionine and tyrosine is made from phenylalanine. When a protein meets the essential amino acid requirements, it has a high biological value. When one or more essential amino acids are present in insufficient amounts to cover human needs, the protein is said to have low biological value. The amino acid that is in shortest supply in relation to need is called the limiting amino acid. Essential amino acid requirements for human growth and health (differentiated for different age groups) are provided by FAO (2012).

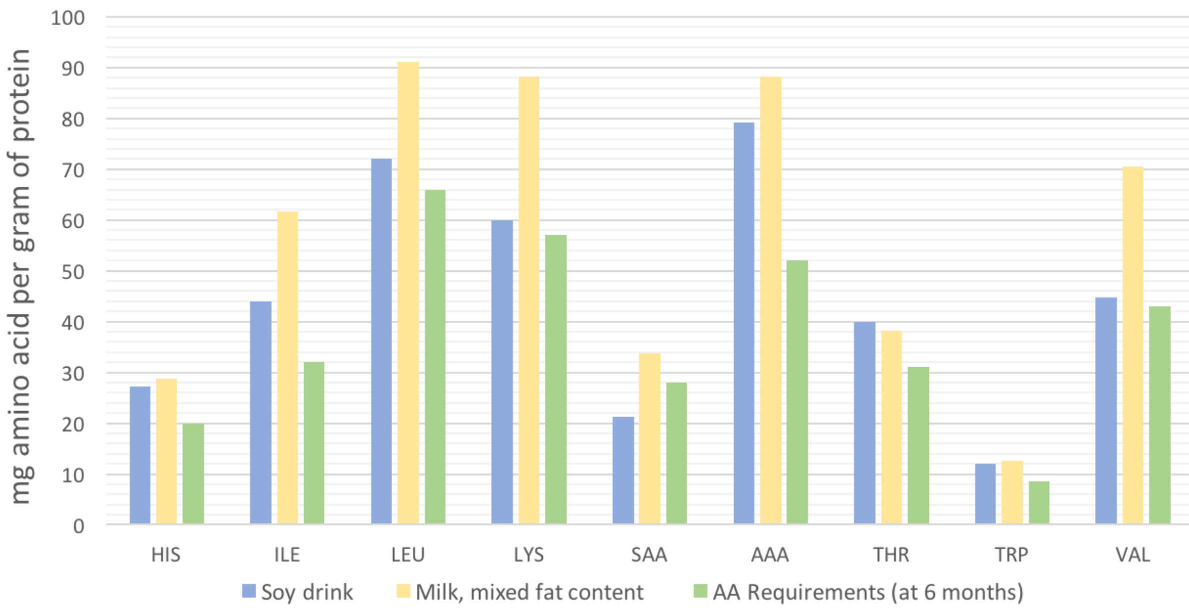

Fig. 5.1. Content of essential amino acids (mg per g protein) in soy drink and milk relative to the dietary requirement. Data compiled from the Swedish National Food Agency's food composition database, requirements are taken from FAO/WHO (2007). Since the amount of amino acids is expressed per gram of protein, the water content of the products compared does not influence the comparison. AA=amino acid, His=Histidine, Ile=Isoleucine, Leu=Leucine, Lys=Lysine, SAA=sulphur amino acids (methionine+cysteine), AAA=aromatic amino acids (tyrosine+phenylalanine), Thr=Threonine, Trp=Tryptophan, Val=Valine[32].

[32]Fig. 5.1 should be interpreted in two ways: first is the amount of amino acids (AA) per gram of protein. This is one way (although other methods exist) to compare the profile of amino acids from different protein sources, here presented for soy and milk protein. Secondly, since these values in themselves are difficult to interpret without any frame of reference, the human AA requirement is also shown as amount per gram of protein. Thus, if protein intake is sufficient to meet the nitrogenous need of the body (since protein is the only important deliverer of nitrogen) and if protein intake is from a single protein source, the amino acid profile should meet the requirement seen in Fig. 5.1.

In general, foods of animal origin (especially milk and egg protein) have higher biological value and digestibility than foods of plant origin, although the differences are small. Table 5.3 shows estimated 'true ileal digestibility'[33] for some different types of food.

Table 5.3. Estimated protein digestibility of different foods.
Several values for a given food indicate results from different studies

Food	**True ileal digestibility**
Milk protein[1]	95%
Casein[1]	94.1%
Soy protein[1]	91.5%
Pea protein[1]	91.5%
	89.4%
	90%
Wheat protein[1]	91.5%
	85%
Lupin protein[1]	90%
Rapeseed protein[1]	84%
Rice, milled[2]	88%
Oatmeal[2]	86%
Peanuts[3]	94%
Soy flour[3]	86%
Soy protein isolate[3]	95%
Wheat gluten[3]	99%

[1]FAO (2012)
[2]Bienvenido (1998)
[3]FAO and WHO (2007)

Fat

The fat content in dairy products can vary. Low-fat varieties are available for almost all types of dairy products. The same can be said for plant-based dairy alternatives. The difference is in the quality of fat[34]. Dairy products are predominantly high in saturated fat, whereas plant-based products are low in saturated fat and high in unsaturated fat. The exception is plant-based dairy alternatives based on coconut.

[33]Protein digestion starts in the stomach, where proteins are denatured by the acidic environment. Enzymatic digestion also occurs in the stomach. Digestion of peptides continues in the small intestine by several different enzymes. Amino acids (and also to some extent actual peptides) are absorbed by the cell wall and transported into the blood. Some protein remains in the digestive system and reaches the colon, where it is degraded into peptides and amino acids by the gut bacteria. When measuring protein digestibility, the fraction of absorbed protein in the small intestine, called the true ileal digestibility, is often considered the most physiologically relevant (but not always) parameter after ingestion, since colonic proteolysis by bacteria overestimates total protein digestibility. When true ileal digestibility is taken into account, the global quality score is DIAAS, recognised as the best method by WHO, but data are lacking to create a large database of DIAAS for all foods (FAO, 2013)

[34]The recommendation from most health agencies has long been to limit the intake of saturated fatty acids (SFA). Lately, however, there has been some controversy around this recommendation, as some recent studies found no positive health effects on decreased intakes of SFA, especially if SFA was replaced by carbohydrates. However, the Scientific Advisory Committee on Nutrition in the UK has just completed a major review of all evidence and has concluded that there is no reason to change the recommendation (SACN, 2018). However, its review did not consider the type of SFA and research indicates that there might be considerable differences between different types of SFA (Zelman, 2011).

Fibre

Molecularly speaking, fibre[35] comprises different combinations of indigestible starch and sugars and is only present in plant-based food; almost no animal food contains fibre as it is defined today. The European Food Safety Authority (EFSA) defines fibre as "*non-digestible carbohydrates plus lignin*", with four different classes of fibre. Most plant-based dairy alternatives are also low in fibre content, as most fibre is lost during processing. However, the oat drink company Oatly has patented a way to retain loose oat fibre, beta-glucans, in their products. Beta-glucans have documented health-promoting effects (Chen and Raymond, 2008; Shen et al., 2016).

Vitamins

When comparing milk with plant-based milk alternatives on the basis of vitamin content, the fortification status of the plant-based products will have a major impact on the result (see section 5.1.4 and Appendix G for more information on fortification). Full-fat milk contains the important vitamins A and D, while low-fat milk is usually fortified with these. All dairy products also contain B12 in substantial amounts. Unfortified plant-based dairy alternatives lack vitamin A, D and B12 entirely, although a large percentage of the products on the market are fortified, hence reaching the same levels as milk for vitamin D and B12 (and vitamin A for fortified oat drink). Soy drink is unique as it provides more riboflavin, folate, vitamin E and vitamin K than milk even when unfortified.

Minerals

As with vitamins, the fortification status of plant-based products will have an obvious impact on the comparison with milk. Unfortified plant-based drinks are low in calcium. Almonds and soybeans are naturally rich in calcium, but during production (adding water and grinding) some of the calcium is lost. As regards magnesium, phosphorus, potassium and zinc, all plant-based drinks are low in these minerals compared with milk, but unfortified soy drink is only slightly lower than milk for these minerals. All plant products contain more iron than milk, with soy drink excelling at almost 0.4 mg per 100g. To put this in perspective, if consumers were to consume soy drink in the same quantity as milk, this would provide 6-11% of their daily recommended intake of iron. On the other hand, cow's milk contains more selenium, zinc and iodide than any of the plant-based products. Calcium is present in fortified plant-based drinks in similar amounts as in milk. Phytate (or phytic acid) is also a compound that is ubiquitous in unrefined plant food, which can contribute to lower bioavailability of minerals. However, due to heating during the production of plant-based dairy alternatives, phytates are removed. The actual concentration of phytate in soy drink is very low (0.05-0.09%) and is therefore unlikely to be a major inhibitor of calcium absorption in fortified soy products (Zhao et al., 2005).

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[35] Fibre was long seen as somewhat of an 'inert' nutrient, meaning that it only served through its 'bulking' effect, leading to eased bowel function and, for viscous fibre, increased satiety and reduced glycaemia and insulinaemia, despite lower energy intake. Today, however, fibre has undergone a 'renaissance', since researchers have managed to identify several different types of fibre with distinct physiological effects. This renaissance has occurred concomitantly with increasing knowledge of the human gut microbiota and the role of gut bacteria for human health and development of diseases. Since fibre cannot be broken down by the human digestive system, these compounds pass through down to the gut microbiota, which feed on undigested fibre, supplying the colon with (healthy) by-products from the fermentation of fibre.

Sugars

Cow's milk contains more sugars than the plant-based alternatives listed in Table 5.1. These sugars come in the form of lactose. The lactose molecule consists of one part glucose and one part galactose and this configuration of molecules gives lactose a lower glycaemic index (less pronounced glucose response) than refined sugar (saccharose) (Foster-Powell et al., 2002), which is used in plant-based dairy alternatives.

Isoflavones

Isoflavones are one of three types of phytoestrogens present in foods, the others being lignans and coumestans. Isoflavones are present in soya, but they can also be found in legumes such as chickpeas and lentils. The chemical structure of isoflavones shows similarities to the structure of oestrogen, but these two have clear differences. There are two types of oestrogen receptor (ER) in the human body, alpha (ERα) and beta (ERβ) receptors. The hormone oestrogen can bind to both receptors. Under normal consumption and physiological conditions, isoflavones from soy bind mainly to Erβ, but at lower affinity than oestrogen (Kuiper et al., 1998). This distinction is important, since ERα and ERβ have opposing physiological effects, where ERα exhibits an oestrogen-like effect and ERβ has *anti*-oestrogen like properties (Oseni et al., 2008' Messina, 2016). Due to the anti-oestrogenic effects of isoflavones, they are believed to contribute to a lower risk for cancer in some organs associated with these receptors (such as breast and prostate cancer) in relation to soy intake (Messina, 2016).

5.1.2 Health effects

An extensive body of research has investigated the health effects of dairy products (Dong et al., 2011a; Dougkas et al., 2011; Abargouei et al., 2012; Beer, 2012; Chen et al., 2012; Aune et al., 2012, 2013, 2015; Dror, 2014; Genkinger et al., 2014; de Goede et al., 2015, 2016; Guo et al., 2015; Alexander et al., 2016; Drouin-Chartier et al., 2016; Gijsbers et al., 2016; Lu et al., 2016a, 2016b; Pimpin et al., 2016; Thorning et al., 2016; Wang et al. 2016a, 2016b; Harrison et al., 2017; Onvani et al., 2017; Bian et al., 2018). As plant-based alternatives to dairy are a novel concept, much fewer health studies are available for these products specifically. Soy drinks and soy products are the exception. These have a very ancient pedigree in South and Southeast Asia, so epidemiological data on these types of products are more common, including studies on Western populations (Jacobsen et al., 1998; Shu et al., 2001; Wu et al., 2002, 2008; Cheng et al., 2005; Fournier et al., 2007; Korde et al., 2009; Harland and Haffner, 2008; Dong and Qin, 2011; Matthews et al., 2011; Taku et al., 2011; Tokede et al., 2015; Li et al., 2016; Tranche et al., 2016; Yu et al., 2016; Morency et al., 2017; Zhao et al., 2017; Applegate et al., 2018). In this section, we briefly summarise some of this evidence. While we recognise the need to perform a more comprehensive review of health effects of dairy products and plant-based dairy alternatives in order to identify where the potential risks and benefits arise in relation to different health outcomes, that was a too great a task for this report.

In a recent (non-systematic) review by Thorning et al. (2016), the health effects of dairy consumption on human health were summarised. Their overall conclusion was that dairy products provide important nutrients with positive health effects with regards to several non-communicable diseases, e.g. that dairy consumption is correlated with lower risk of obesity in children (but not in adults) and lower risk of developing type 2 diabetes (especially consumption of fermented dairy products and cheese). An advantage of dairy consumption on weight loss is also seen, but only under conditions of energy restriction. High milk consumption (200-300 mL/day) has no effect on the risk of cardiovascular disease, with a positive effect of milk consumption on the risk of stroke and hypertension. The effect of dairy consumption on bone health is positive, but only to a certain extent. Dairy consumption have a positive effect on the bone mineral density of children and adolescents, but no protective effects on fracture risk in adults (Thorning et al., 2016). The absence of protective effects in adults might be explained by the fact that there are several important factors for determining bone fracture events (such as physical activity and intake of vitamin D) and not solely bone mineral density. According to the World Cancer Research Fund, there is probable evidence that dairy consumption decreases the risk of colorectal, bladder, gastric and breast cancer, whereas no association has been found for pancreatic, ovarian or lung cancer. The evidence as regards dairy consumption and prostate cancer risk is inconsistent. As regards dairy consumption and all-cause mortality, there seems to be no consistent evidence in either direction.

In a review by Messina (2016), the health effects of soy-based foods were investigated on the basis of the best available evidence in epidemiological research. Soy protein has been shown to have beneficial effects on risk factors for cardiovascular disease, including improved lipid levels, lower blood pressure, improved endothelial function and less arterial stiffness. However, effects on risk factors do not necessarily translate into lowered incidence of disease in all types of populations (most studies investigating soy are conducted on women). With regard to coronary heart disease (CHD) events, there are mixed findings on the effect of soy consumption. There may be an important interaction between the type of foods soy products replace in the high consumption category, which might alter the health effects of soy. There is also a possibility that, due to the unique properties of soy with its high isoflavone content, the health effects of soy consumption are more pronounced in women than men. Furthermore, soy intake has been shown to decrease the risk of breast cancer, prostate cancer (Applegate et al., 2018) and colorectal cancer (Yu et al., 2016). There has been some concern about soy intake by breast cancer patients, as it has been suggested that the isoflavones in soy might adversely affect the prognosis for such patients. However, the evidence for this is only derived from animal studies, whereas some epidemiological studies have found that soy intake could improve the prognosis in breast cancer patients. In addition to the potential role of soy foods in chronic conditions, as mentioned above, there may be beneficial effects of soy food in reducing menopause symptoms and improving mental and skin health (Messina, 2016).

Many plant-based dairy alternatives include functionally active components with health-promoting properties, such as beta-glucans in oats and alpha-tocopherol in almonds. See Sethi et al. (2016) for a review of these.

5.1.3 Authorised health claims

Food authorities such as the European Food Safety Authority (EFSA) and the US Food and Drug Administration (FDA) evaluate the available evidence on the 'healthfulness' of different foods, in order to test different health claims that food product manufacturers want to use in marketing.

Health claims related to dairy and plant-based dairy alternatives include the following:

- Improved lactose digestion for yogurt in the EU: Scientific Opinion on the substantiation of health claims related to live yoghurt cultures and improved lactose digestion (ID 1143, 2976) pursuant to Article 13(1) of Regulation (EC) No 1924/2006)
- Positive health claims for oat beta-glucan in the EU: Scientific Opinion on the substantiation of a health claim related to oat beta glucan and lowering blood cholesterol and reduced risk of (coronary) heart disease pursuant to Article 14 of Regulation (EC) No 1924/2006
- A 'Health claim about Soy Protein and Cholesterol Lowering' (approved by Health Canada's Food Directorate on 23 April 2015). According to Health Canada's Food Directorate, scientific evidence exists to support the health claim that consumption of soy protein helps to lower blood cholesterol levels. The Directorate based its decision on literature research covering the period January 1980-March 2010. All foods containing soy protein, such as isolated soy protein, soy protein concentrate, textured soy protein and soy flour, but also foods made from the whole soy bean, are eligible for the health claim. Foods containing at least 6 g of soy protein per reference amount and per serving, and also complying with a list of conditions regarding the presence of recommended nutrients, maximum levels of cholesterol, alcohol, etc., are allowed to bear the health claim.

5.1.4 Fortification of dairy and plant-based drinks

Since the nutritional quality of plant-based drinks is dependent on whether they are fortified or not, the question of fortification is central to comparison between dairy and plant-based dairy alternatives. The most common nutrients used in fortification are calcium, riboflavin, vitamin D and vitamin B12. Fortification strategies vary in different countries, based on the nutritional challenges of a specific population and differences in jurisdiction surrounding the fortification of products. One example of how micronutrients and fortification are important and context-specific is provided by the WWF UK Livewell Plate project. In this analysis, cheese consumption was reduced compared with the current UK diet, while other dairy products were slightly increased for adults. One of the reasons for this was that dairy products are the most important source of iodine in the current UK diet, and intake of this trace element is currently below the requirement. However, in countries where iodised table salt is commonly used (such as Sweden, Belgium, the Netherlands), iodine would not be a reason to keep a high dairy level in the diet.

There is an ongoing debate on fortification of foods and whether intake of micronutrients already present in foodstuff is better for health than micronutrients provided through fortification. Research suggests that whole foods are in general superior in promoting health than supplements of vitamins and minerals, and that some supplements like vitamin E, selenium and beta-carotene are even associated with an increased rate of cancer in some populations (Harvie, 2014). This can probably be explained by 1) intake of micronutrients as part of food not resulting in overconsumption, whereas intake of supplements can result in overconsumption; and 2) whole foods containing a wide array of bioactive substances, some of which are still unknown to the medical community. Bioactive compounds can elicit e.g. more antioxidant power when combined than when evaluated individually. The so-called 'matrix effect' takes into account the structural organisation of whole foods, which elicit different health effects than nutrients exert on their own (Thorning et al., 2017).

The bioavailability of naturally occurring compounds compared with fortification agents is another issue, but lower bioavailability can usually be compensated for by higher fortification levels (further discussed in Appendix G). There are several cases of successful public health interventions where staple foods have been fortified and have in practice eliminated diseases, as is the case for iodine fortification of salt in Sweden and goitre. What does raise concern is the emerging evidence on calcium supplementation and cardiovascular events. In a study by Bolland et al. (2013), an increased risk of cardiovascular events (non-lethal included) of between 17-31% was seen for calcium supplementation, depending on the outcome. The proposed mechanism is how calcium is delivered; dietary calcium is incorporated in organic compounds, whereas calcium supplements are carried by an associated salt, thus being inorganic. This different molecular context is thought to give rise to high serum concentrations of calcium, which might then exert detrimental effects on the cardiovascular system. However, a later review by Weaver (2014) summarised the evidence for calcium supplements and cardiovascular disease risk and concluded that the totality of the epidemiological evidence does not constitute a strong case for concern. The National Food Agency in Sweden, America's USDA, the UK's Eatwell Guide, the Wheel of Five in the Netherlands and the healthy living food triangle from Flanders all recommend fortified plant-based products as an alternative to dairy products.

5.2 Environmental impacts of dairy and plant-based dairy alternatives

In general, scientific studies on the effect of diet on social and economic dimensions are very scarce, while studies focusing on the impact on the environment in general and climate in particular have grown rapidly in recent years. Here we summarise and give examples of results of studies comparing dairy and plant-based dairy alternatives. The section is divided into three parts; comparison on a product-to-product basis, either per unit mass or based on nutrient density (section 5.2.1), comparison in a dietary context (5.2.2) and comparison from a production system perspective (section 5.2.3).

5.2.1 Comparison on a product-to-product basis

The most common way of comparing food products in on the basis of mass, commonly per kg. In LCA, this unit of comparison is called the functional unit. However, different food products provide different 'functions', e.g. some provide a lot of protein, while others are low in protein but rich in other nutrients and so on. Therefore comparing foods based on mass has been criticised for failing to consider the function of foods, leading to 'unfair' comparisons (Notarnicola et al., 2017). An alternative is to compare foods based on their energy or protein content or their nutrient density. Choice of functional unit can strongly influence the comparison of different foods (Masset et al., 2015).

The choice of functional unit is not straightforward. For example, as the average protein intake in many high-income countries is far beyond recommendations and as many consumers also over-consume food in general, it could be argued that the prime function of food in such settings is to supply pleasure rather than nutrients, which could justify the use of mass as the functional unit after all. In addition, when consumers shop for food they shop for quantities rather than nutrients, for example a serving of sausage in a meal is often the same size as a serving of pure meat, although the protein content in the sausage might be considerably lower. In low-income countries, livestock have additional functions to providing food, e.g. providing manure for fuel, draught power and financial insurance, which needs to be considered in comparisons of different foods or production systems (Weiler et al., 2014). Hence, the choice of functional unit is highly dependent on the context and aim of the study.

For LCA on milk, a metric that corrects for the varying fat and protein content of the milk is commonly used, e.g. energy-corrected milk (ECM) (Sjaunja et al., 1990). For comparisons of milk with plant-based dairy alternatives, there is no consensus on how that should be done and studies to date have used comparisons per kg and different nutrient profiling methods.

Comparison per kg product

Climate impact

In a meta-analysis and systematic review by Clune et al. (2017), 369 studies were reviewed to investigate the carbon footprint (measured as the global warming potential (GWP) in CO_2e per kg product) of 168 varieties of produce. The results comprise 1718 individual values, of which those relevant for dairy and plant-based dairy alternatives are presented in Table 5.4. The carbon footprint for the dairy product category was based on 90 LCA studies with 341 values for milk. The carbon footprint included emissions up to the regional storehouse.

Gerber et al. (2013) present estimates of the carbon footprint of dairy, in aggregated form and separated for ruminant species and place of production (Table 5.4). To compare milk with differing content of fat and protein, their estimates are fat- and protein-corrected, i.e. they are converted to a standard with 4% fat and 3.3% protein content. The estimates reported by Gerber et al. (2013), like those reported by Clune et al. (2017), include post-harvest emissions, such as transport and processing. However, the contribution of these emissions is small and was estimated by Gerber et al. (2013) to be 6.1% of the total carbon footprint of cattle milk. Variations in the carbon footprint of dairy milk between regions reflect the intensity of production, with more extensive systems releasing more GHG emissions per kg milk produced, mainly due to lower milk yields.

While Clune et al (2017) compiled results from case study LCAs, Gerber et al. (2013) performed a global top-down modelling study that covered both extensive and intensive systems. This explains the large difference in the world average carbon footprint of dairy (2.8 in Gerber et al. (2013) and 1.39 in Clune et al. (2017)), as LCA on extensive systems are uncommon and thus the average value in Clune et al. (2017) is biased towards high-income settings. In Clune et al. (2017), only five studies on milk production systems in Central and South America are included and only two for Asia and Africa. The same lack of studies applies for milk from other animal species, and also for processed dairy products like cream and butter.

Table 5.4. Global warming potential (GWP) values for dairy products, adapted from Clune et al. (2017) and Gerber et al. (2013) (SD=standard deviation, OC=Oceania, WE=Western Europe, LAC=Latin America and the Caribbean, ESEA=East and Southeast Asia, SSA=Sub-Saharan Africa)

	CO_2e per kg product		Statistics for Clune et al.			
Dairy product	**Gerber et al. (2013)**	**Clune et al. (2017) (mean)**	**SD**[a]	**Min-Max**	**No. of studies**[a]	**No. of values**[a]
Milk: world average	2.8[b]	1.39	0.58	0.54-7.50	77	262
Milk: Australia and New Zealand	~1.6 (for OC)	1.19	0.15	0.94-1.40	10	10
Milk: North America	~1.8	1.34	0.40	0.94-2.06	11	19
Milk: British Isles	~1.7 (for WE)	1.26	0.23	0.88-1.99	16	35
Milk: Europe	~1.7 (for WE)	1.32	0.29	0.54-2.39	52	175
Milk: Central and South America	~3.9 (for LAC)	1.69	0.61	1.14-3.30	5	10
Milk: Asia	~2.4 (for ESEA)	2.53	1.09	1.38-4.60	2	7
Milk: Africa	~9 (for SSA)	3.34	1.90	1.02-7.50	2	5
Yoghurt	-	1.43	0.25	1.17-2.00	7	11
Buffalo milk	3.4[b]	3.75	0.86	2.87-5.20	1	7
Sheep and goat's milk	6.5	-				
Cream	-	5.32	1.62	2.10-7.92	3	4
Cheese	-	8.86	2.07	5.33-16.35	22	38
Butter	-	11.52	7.37	3.70-25.0	4	8
Plant-based products						
Soy milk	-	0.88	0.27	0.66-1.40	2	8
Almond, coconut milk	-	0.42	0.03	0.39-0.44	1	4

[a]These only relate to values provided by Clune et al. (2017).
[B]This value includes post-harvest emissions such as transport and processing.

The carbon footprint of milk is sensitive to several LCA modelling choices, most importantly the allocation of emissions between milk and meat, which can be based on economic or physical relationships, e.g. fat and protein content in the meat and milk, or the percentage of feed needed to cover milk production (Cederberg et al., 2003). Another approach is to use 'system expansion', in which the emissions caused by the product that the dairy meat 'replaces' on the market, e.g. beef from suckler herds, pork, poultry or potentially even legumes (Flysjö et al., 2011), are subtracted from the total emissions from the dairy system, hence isolating the emissions attributed to the milk (Fig. 5.2).

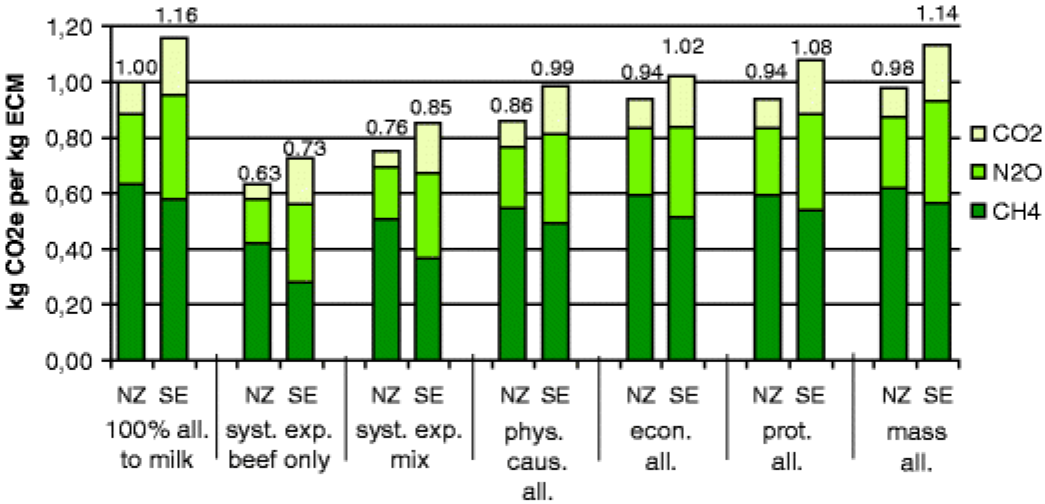

Fig. 5.2. Carbon footprint of milk from New Zealand (NZ) and Sweden (SE), estimated using different methods to allocate emissions between milk and meat. From Flysjö et al. (2011).

Another issue to consider is that in 2013, the International Panel on Climate Change (IPCC) changed the factor used to weight methane into the common unit of carbon dioxide equivalents (CO_2e) from 25 to 28 (34 including carbon-climate feedbacks) (100-year perspective; Myhre et al., 2013). Most studies published to date, including Gerber et al. (2013) and all studies in Clune et al. (2017), have used the old factor of 25 (or the even older factor of 23). Applying the new factor of 34 would mean an increase in the carbon footprint of dairy milk of approximately 20%. There are also other metrics for weighting the different greenhouse gases that can give quite different results (Persson et al., 2015).

We were unable to find any peer-reviewed studies published in scientific journals on the climate impact of plant-based dairy alternatives. In the review by Clune et al. (2017), only two studies on plant-based dairy alternatives were included. One of these, by Feraldi et al. (2012), is from a conference and to our knowledge not is available online. The other is a report from Tesco in the UK which lists the carbon footprint of a large set of Tesco products, including six own brand soya drinks whose carbon footprint ranged from 0.7 kg CO_2e for unsweetened soya drink to 1.4 kg for its organic counterpart (Tesco, 2012). We summarise the grey literature we found on the environmental impact of plant-based dairy alternatives later in this section.

Ecotoxicity impacts

Nordborg et al. (2017) evaluated freshwater ecotoxicity from the production of six different foods in Sweden; minced pork, chicken fillet, minced beef, milk, wheat bread and pea soup. They found that Swedish milk had an impact of the same magnitude as cereals and legumes cultivated in Sweden when compared per kg product (3-4 times higher for milk when compared per kg protein), while the impact from meat, especially pork and chicken, was almost 100 times higher, mostly as an effect of the use of heavily sprayed soy as animal feed. In contrast to the climate impact, the ecotoxicity impacts are a direct consequence of the management of the production system, rather than whether it is an animal or plant-based product. For example, organic systems, regardless of the product, have very low ecotoxicity impacts.

Impacts on water resources

Mekonnen and Hoekstra (2011) quantified the green (rainwater), blue (surface or groundwater) and grey (water needed to assimilate pollutants) water footprint of global crop production in a spatially explicit way for the period 1996-2005. Mekonnen and Hoekstra (2012) assessed the water footprint of animal products, considering different production systems and feed composition per animal type and country. Ercin et al. (2012) studied the water footprint of soy milk produced in Belgium from soy bean grown in Canada and France. Results from these studies are summarised in Table 5.5, which also presents data on water footprint for almonds, oats, rice and soybeans. In order to compare drinks made of these commodities with milk and soy drink, it has to be considered how much of these products are used per ton of drink, as well as the water footprint from other ingredients (e.g. vegetable oil) and from processing (which is usually low compared with that of raw material production). For oat drink, approximately 0.2 kg of oats is needed per kg of oat drink (Florén et al., 2013). Using this value, the data in Table 5.5 indicate, very approximately, that drinks made of oats and soy have a lower blue water footprint than dairy milk, while the impact of rice drink is of the same magnitude as that of dairy milk and that of almond drink is considerably higher. However, metrics that take water scarcity into account show that milk can be produced with very little impact on water resources (Ridoutt et al., 2010), which shows that where production takes place is crucial for water use impacts. See Appendix E3 for more on water use methodology.

Table 5.5. Water footprint (m^3 per tonne). From Mekonnen and Hoekstra (2011*, 2012**) and Ercin et al. (2011)***

Product	Green	Blue	Grey
Milk: world average grazing**	1087	56	49
Milk: world average mixed**	790	90	76
Milk: world average industrial**	1027	98	82
Soy drink: world average*	3574[1]	123[1]	65[1]
Soy drink: Belgium***	276	10	10
Soybeans: world average*	2037	70	37
Oats: world average*	1479	181	128
Rice: world average paddy rice*	1146	341	187
Almonds: world average shelled or peeled*	9264	3816	3015

[1]These values seem unreasonably high, as the water footprint of soy milk should not be higher than the water footprint of soy bean.

Nitrogen footprint

Leip et al. (2014) modelled the nitrogen footprint of 12 food commodities in the EU and found that dairy products on average had a nitrogen footprint of approximately 30 g N per kg product, while the corresponding value for cereals and legumes was approximately 10-20 g N per kg product, which implies that drinks made of these raw materials have a nitrogen footprint in the range or 1-4 g N per kg product. Legumes had the lowest 'nitrogen investment factor' (quantity of new reactive nitrogen required to produce one unit of nitrogen in the product) of all foods, i.e. 1-2 kg N per kg of N in legumes, compared with approximately 6 kg N per kg of N in milk. See Appendix E5 for more on metrics of impacts on biogeochemical flows.

Biodiversity

Quantifying the impact on biodiversity from food production is challenging for many reasons. For example, biodiversity impacts arise from several impact pathways (e.g. land use, use of pesticides, water pollution, climate change), biodiversity includes a diversity of ecosystems, species, breeds and genes, and determining the reference state to which to compare impacts is often not straightforward. Chaudhary and Kastner (2016) estimated species loss embodied in global food trade for four vertebrate taxa. Their analysis, based on number of species lost due to land use, covered 170 crops in 184 countries. For livestock, only the crop part of the feed was included in their analysis, i.e. biodiversity impacts from livestock grazing were not included. The results showed the highest impacts for cropland use in tropical regions, followed by temperate regions and the lowest impacts for boreal regions, with a variation of over six orders of magnitude. Country-specific biodiversity impacts per ton of crop are presented in Chaudhary and Kastner (2016). Some results relevant for dairy production and the production of plant-based dairy alternatives are summarised in Table 5.6.

Table 5.6 Biodiversity impact from one tonne of crop production. From Chaudhary and Kastner (2016)

Product	No. of species lost
Almonds: France	$1.4 * 10^{-5}$
Almonds: USA	$1.2 * 10^{-6}$
Rice: France	$5.8 * 10^{-7}$
Rice: Vietnam	$3.3 * 10^{-6}$
Oats: France	$1.6 * 10^{-7}$
Oats: Sweden	$1.2 * 10^{-7}$
Rapeseed: Sweden	$2.9 * 10^{-7}$
Forage crops: Denmark	$6.8 * 10^{-8}$
Soy: Brazil	$3.0 * 10^{-7}$
Soy: China	$9.4 * 10^{-7}$
Soy: Canada	$3.7 * 10^{-7}$
Soy: USA	$2.9 * 10^{-7}$

Chaudhary and Kastner (2016) do not present the impact for animal products explicitly, but these can be calculated based on the crops in livestock diets. Very approximately, assuming that a typical dairy system in Europe uses approximately 0.4 kg of cereals, 0.03 kg of soy (from Brazil) and 0.4 kg of forage crops per kg milk produced (based on data from Sweden; Cederberg et al., 2009), this gives a biodiversity impact (number of species lost) of 8.4×10^{-8} based on the values in Table 5.6. In comparison, oat drink, under the assumption that 0.2 kg of oats and 0.1 kg rapeseed is used per kg of oat drink, gives a biodiversity impact of 5.8×10^{-8}. Hence, assessments of biodiversity impacts using this methodology yield results of the same magnitude for dairy milk and oat drink from Europe. However, almond drinks and rice drinks would score one or two orders of magnitude higher.

Studies on plant-based dairy alternatives in the grey literature

Several food manufacturers have commissioned LCA studies on their products for internal or marketing purposes. These are commonly performed by consulting companies and vary in quality and transparency. Some are available online. We summarise the results from such studies in Table 5.7. The climate impacts of plant-based drinks are within the range 0.3-0.6 kg CO_2e per kg or litre of drink, while those of milk are within the range 1.3-1.7 kg CO_2e per kg milk in these studies. There is one exception; the report from Tesco gives considerably higher values for soy drink.

Milk also shows higher impacts in most other impact categories, with a few exceptions. Freshwater eutrophication for one type of Swedish oat drink is higher than for Swedish milk, due to electricity generation in Germany (where the oat drink is produced) emitting phosphate into waterways. Use of water in Germany, rather than Sweden, also explains the higher water use for the oat drink compared with milk, since that study accounts for water scarcity in different countries. Furthermore, water use seems to be higher for almond drink than for milk, while the LCA commissioned by Alpro on soy drink and milk shows that ionising radiation and resource depletion[36] are lower for milk than for soy drink.

Table 5.7. Summary of the environmental impacts of plant-based dairy alternatives, according to manufacturer-commissioned life cycle assessments (LCA). Highest value for each impact category marked in pink

Study	Results: Impact category	Unit	Ripple pea drink	Almond	Soy drink	Dairy milk
Life Cycle Assessment of Ripple Non-Dairy Milk https://www.ripplefoods.com/pdf/Ripple_LCA_Report.pdf (Retrieved May 24 2018)	Carbon footprint	g CO_2e (per kg protein)	387 (11.7)	454 (110)	476 (14.5)	**1.467** (44.4)

Study	Impact category	Unit	Aseptic oat drink	Fresh oat drink	Milk
Oatly Florén et al. (2013). Internal confidential report) Data for 1 L of drink; covers all life cycle stages including waste management of packaging at the consumer	Carbon footprint	kg CO_2e	0.3	0.4	**1.3**
	Primary energy use	MJ-eq	7.7	9.2	**19.6**
	Terrestrial eutrophication	molc N eq	0.005	0.006	**0.103**
	Freshwater eu.	kg P eq	0.00010	**0.0019**	0.00008
	Marin eu.	kg N eq	0.002	0.002	**0.006**
	Acidification	mol H+ eq	0.002	0.002	**0.024**
	Ozone formation	kg NMVOC eq	0.001	0.002	**0.004**
	Land use	m^2	0.6	0.6	**2.9**
	Water use	m^3 water eq	0.0005	**0.008**	0.0009

Study	Impact category	Unit	Coconut milk	Almond drink	Soy drink
Feraldi et al. (2012). Life Cycle Assessment of Coconut Milk and Two Non-Dairy Milk Beverage Alternatives. Franklin Associates.	Energy demand	MJ eq	1.91	1.39	**3.62**
	Global warming	kg CO_2e	0.1	0.11	**0.61**
	Ozone depletion	kg CFC-11 eq	$2.4*10^{-9}$	$1.8*10^{-9}$	**$3.2*10^{-9}$**
	Water consumption	litre H_2O eq	6.81	**126**	50.8
	Acidification	H+ moles eq	0.057	0.05	**0.09**

[36] The higher resource depletion for soy drink is explained by longer transport distances for soy compared with milk and therefore a higher need for lead in the maintenance of trucks and for indium, a metal with a high characterisation factor.

http://lcacenter.org/lcaxii/final-presentations/719.pdf (Retrieved March 13 2016). Values are per 0.5 gallon (2.27 L) of drink.	Eutrophication — kg N eq — **$6.7*10^{-5}$** — $4.1*10^{-4}$ — $1.5*10^{-4}$ Smog — kg NOx eq — **$8.1*10^{-4}$** — $3.9*10^{-4}$ — 0.0014 Solid waste — kg SW eq — 0.0087 — **0.0095** — 0.023
Ho et al. (2016). Almond milk vs cow milk - Life cycle assessment. Environment 159. Values are per litre of drink. Link: https://www.ioes.ucla.edu/wp-content/uploads/cow-vs-almond-milk-1.pdf (Retrieved May 24 2018)	**Impact category — Unit — Almond drink — Cow's milk** Global warming — kg CO_2e — 0.36 — **1.67** Water consumption — litre H_2O — **6100.6** — 291.5
Kerkhof and Terlouw (2015). Ecofys. Life Cycle Assessment of Alpro Plain Calcium Soy Drink and Dairy Milk in Belgium, Germany, the Netherlands and the United Kingdom.Values are per litre of drink. Commissioned by Alpro.	**Impact category — Unit — Alpro soy drink — Dairy milk UHT — Fresh dairy milk** Climate change — kg CO_2e — 0.48 — 1.65 — **1.69** Ozone depletion — kg CFC-11 eq — $2.8*10^{-7}$ — $2.67*10^{-7}$ — **$3.25*10^{-7}$** Human toxicity (non cancer) — CTUh — $2.98*10^{-7}$ — $3.14*10^{-6}$ — **$3.15*10^{-6}$** Human toxicity (cancer) — CTUh — $2.16*10^{-8}$ — $3.28*10^{-8}$ — **$3.4*10^{-8}$** Particulate matter — kg PM2.5 eq — $3.26*10^{-4}$ — **$1.2*10^{-3}$** — **$1.2*10^{-3}$** Ionising radiation HH — kBq U235 eq — **0.123** — 0.102 — 0.105 Ionising radiation E (interim) — CTUe — $3.32*10^{-7}$ — $3.49*10^{-7}$ — **$3.57*10^{-7}$** Photochemical ozone formation — kg NMVOC eq — $1.57*10^{-3}$ — $2.22*10^{-3}$ — **$2.23*10^{-3}$** Acidification — molc H+ eq — $4.22*10^{-3}$ — $4.48*10^{-2}$ — **$4.48*10^{-2}$** Terrestrial eutrophication — molc N eq — 0.0139 — **0.196** — **0.196** Freshwater Eutrophication — kg P eq — $1.04*10^{-4}$ — **$2.65*10^{-4}$** — **$2.65*10^{-4}$** Marine eutrophication — kg N eq — $1.59*10^{-3}$ — **$1.43*10^{-2}$** — **$1.43*10^{-2}$** Freshwater ecotoxicity — CTUe — 6.75 — 9.62 — **10.4** Land transformation — kg C deficit — 4.89 — **12** — **12** Water resource depletion — m^3 water eq — $1.8*10^{-3}$ — $2.87*10^{-3}$ — **$2.91*10^{-3}$** Mineral, fossil & renewable resource depletion — kg Sb eq — **$2.46*10^{-5}$** — $2.09*10^{-5}$ — $1.56*10^{-5}$
Tesco (2012). Product Carbon Footprint Summary. Link: https://www.tescoplc.com/assets/files/cms/Tesco_Product_Carbon_Footprints_Summary(1).pdf (Retrieved May 24 2018)	**Soy drink product — Carbon footprint** Tesco fresh sweetened soya milk 1 litre — 0.8 kg CO_2e Tesco unsweetened soya alternative to dairy 1 litre — 0.7 kg CO_2e Tesco calcium enriched soya drink 1 litre — 0.9 kg CO_2e Tesco value unsweetened soya drink 1 litre — 0.7 kg CO_2e Tesco organic U/SWT soya drink 1 litre — 1.2 kg CO_2e Tesco organic SWTND soya drink 1 litre — 1.4 kg CO_2e

As an example of a study that jointly evaluated many aspects of milk and plant-based milk alternatives, here we briefly present results from a report from Healthcare without Harm[37] (2017). In that report, the health, environmental, social justice and animal welfare aspects of dairy and plant-based milk alternatives are assessed. A summary of the results is provided in Table 5.8. The impact of products is defined as positive (moderate or strong), negative (moderate or strong), neutral or debated, and is based on how other products perform in the same category. Rankings are based on the relative per-serving impact of that food group compared with other food groups. Health rankings are based on the extent of research demonstrating health benefits or risks associated with consuming that food type. For the social justice rankings, no product is ranked "positive", given the generally poor labour standards in both domestic and international food production. However, foods that have been associated with serious labour concerns during production are ranked moderately or strongly negative in the report, depending on the extent of the concerns. For animal welfare rankings, strong negatives are attributed to food types associated with significant welfare harms; relative improvements in welfare practices (while taking into consideration new potential harms from these practices) are noted as moderately negative, neutral, or moderately positive, depending on the extent of the difference. Inevitably, the classification system is arbitrary to some extent and rankings are based on subjective norms, although if such classification systems are transparently described and developed with stakeholder involvement, they may be useful for evaluating products from many perspectives. However, grouping all plant-based alternatives into one category is too coarse to give valuable information. In addition, there are many more alternative dairy systems.

Table 5.8. Comparison between dairy and plant-based milk alternatives (MP=moderately positive, SP=strongly positive, MN=moderately negative, SN=strongly negative, D=debated, N/A=not applicable). From Healthcare without Harm (2017).

Dimension	**Dairy, conventional**	**Dairy, grass-fed**	**Plant-based alternatives**
Health	MP(D)	MP(D)	Neutral
Environmental			
Climate	MN (D)	MN (D)	SP
Land use	MP	MP	SP
Resource input	SN	Neutral	MN
Biodiversity	MN	SP	MN
Social justice	SN	Neutral	Neutral (SN cashew)
Animal welfare	SN	Neutral	N/A (MN/D coconut)

[37]Healthcare Without Harm Europe is a non-profit European coalition of hospitals, healthcare systems, healthcare professionals, local authorities, research/academic institutions and environmental and health organisations. It currently has 84 members in 26 countries.

Comparison of environmental impact using nutrient density scores

One way to account for the varying nutrient content in dairy milk and different types of plant-based dairy alternatives when comparing their environmental impacts is to use the nutrient density of the products as a basis for comparison, rather than comparison per kg of food (section 3.4).

Smedman et al. (2010) designed a Nutrient Density to Climate Impact (NDCI) index to compare milk, unfortified soy and oat drink, soft drink, orange juice, beer, wine and bottled carbonated water. They used data on unfortified rather than fortified products in order to minimise error and to enhance generalisability, and suggest that future studies include fortified drinks in similar comparisons when data on GHG emissions are available for these products. The nutrient density score used by Smedman et al. (2010) included three macronutrients (protein, carbohydrates, fat), and 18 micronutrients (retinol equivalents, vitamin D, vitamin E, thiamin, riboflavin, ascorbic acid, niacin equivalents, vitamin B6, vitamin B12, folate, phosphorus, iron, potassium, calcium, magnesium, selenium, zinc, iodine). Fibre was not included. The index did not include nutrients to be limited, e.g. saturated fat or added sugar. The nutrient density was calculated by summarising the proportions of recommended daily intake of each nutrient provided by 100 g of the beverage, multiplied by the proportion of nutrients contributing to more than 5% of value given in the Nordic Nutrition Recommendations. The nutrient density of each beverage was then combined with its GHG emissions to create the NDCI index. Smedman et al. (2010) found that milk had the highest nutrient density in relation to GHG emissions of all the beverages compared (Table 5.9).

Table 5.9. Nutrient density in relation to climate impact. From Smedman et al. (2010)

Food item	Number of nutrients ≥ 5% of NNR	**Nutrient density**	**Greenhouse gas (GHG) emissions**	**Nutrient Density to Climate Impact (NDCI) index**
Milk	9	53.8	99	0.54
Soft drink	0	0	109	0
Orange juice	4	17.2	61	0.28
Beer	0	0	101	0
Red wine	1	1.2	204	0.01
Mineral water	0	0	10	0
Soy drink	3	7.6	30	0.25
Oat drink	1	1.5	21	0.07

In a letter to the editor, Scarborough and Rayner (2010) expressed concern that the NDCI index is flawed, as the ranking of the drinks produced by the index is dependent on an arbitrary choice of threshold for contributing to the Nordic Nutrition Recommendations (NNR). When the threshold is set at a value lower than 5% of the NNR, soy drink achieves the highest NDCI score. Milk achieves the highest NDCI score when the threshold is set at 5 or 10% of the NNR. When the threshold is set at 20% of the NNR, orange juice instead achieves the highest NDCI score.

In a recent study, van Dooren et al. (2017b) proposed a nutrient density index that considers the GHG emissions associated with different foods. Based on the correlation between GHG emissions and nutritional density, van Dooren et al. (2017b) devised a modified nutritional index, the Sustainable Nutrient Rich Food (SNRF) index, where only the six most important nutrients reflecting health and GHG emissions are included: plant protein, saturated fat, essential fatty acids, sodium, fibre and added sugar. The authors claim that this modified index reflects a much more relevant correlation between nutrition and environmental impact. It also creates a foundation for classifying foods into three 'traffic light' categories, as shown in Fig. 5.3.

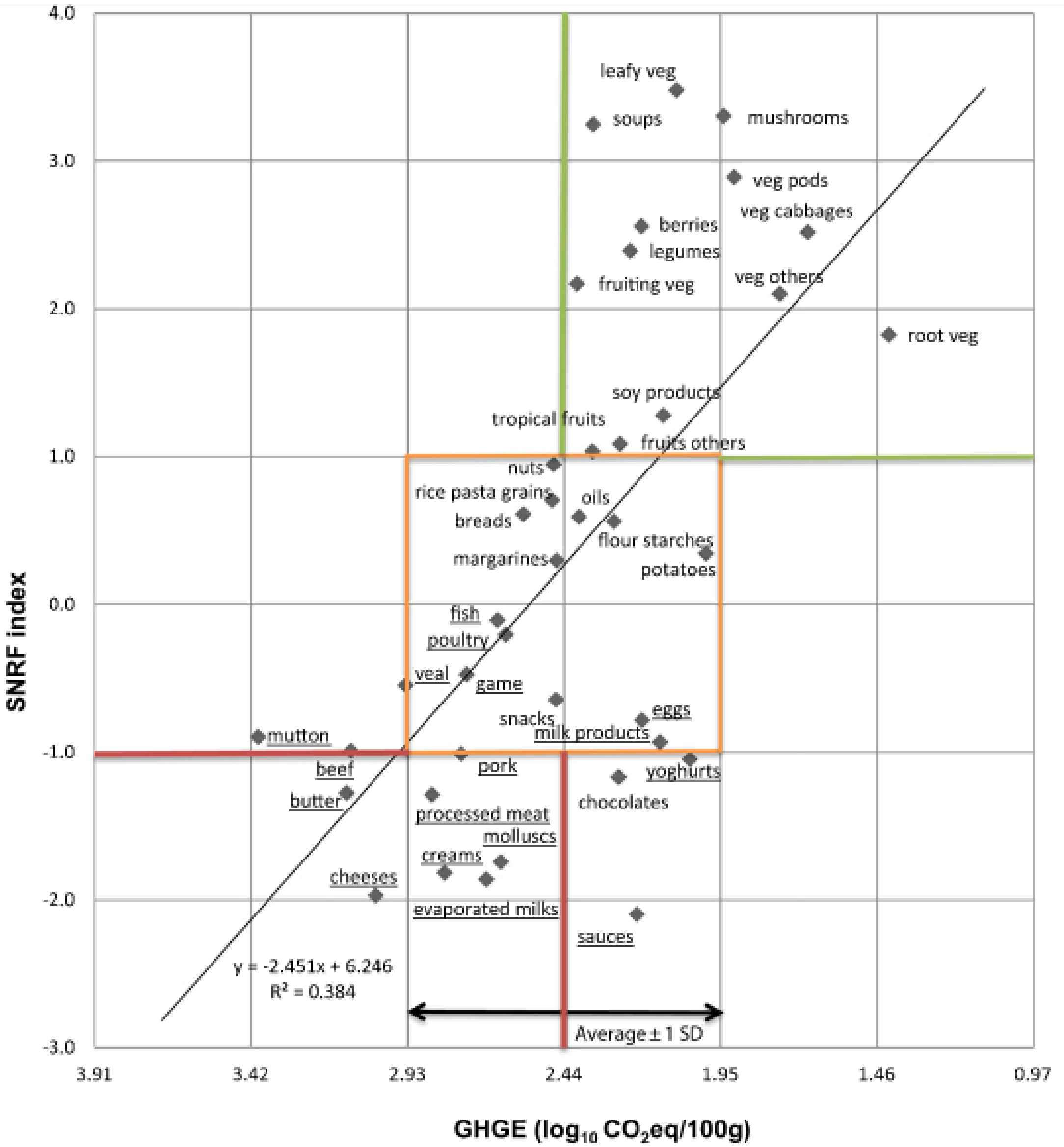

Fig. 5.3. Sustainable nutrient rich food (SNRF) index of different food groups, plotted as a function of greenhouse gas emissions (GHGE). From van Dooren et al. (2017b).

Sonesson et al. (2017) used three different protein-related functional units to compare the climate impact, land use and freshwater ecotoxicity impact of bread, chicken fillet, minced pork, minced beef, milk and pea soup. The functional units were grams of protein, grams of digestible protein and weighted protein quality index (PQI). The PQI considers the importance of the studied product as a provider of essential amino acids (EAAs) in the specific dietary context, hence providing a novel approach for including consideration of protein quality and the dietary context into the comparison of individual food products.

The PQI is created by using product-specific EAA ratios, the EAA ratio for the total dietary intake (in three specific dietary contexts) and the nutritional requirement for each EAA. If a product contains EAAs that are lacking in the diet, the PQI of that specific product will be higher, and vice versa. The three dietary contexts used in Sonesson et al. (2017) were an average Swedish diet, a hypothetical lacto-ovo vegetarian diet and a hypothetical low-meat diet. The total protein content of the average Swedish diet was 136% of recommended intake, while that of the hypothetical lacto-ovo vegetarian diet was 106% of recommended intake. This lacto-ovo vegetarian diet was based on the average Swedish diet, but meat and seafood were replaced with pulses, eggs, and dairy products delivering the same quantity of energy. On an energy basis, meat was replaced by 72% pulses, 16% eggs and 11% cheese. The total protein amount in the hypothetical low-meat diet was 93% of recommended intake. This diet was created by reducing the meat, seafood, and dairy content in the average diet and replacing them in part with low-protein foods supplying 70% of the energy. Part of the meat, seafood and dairy content was isocalorically replaced with 50% whole wheat bread, 30% tubers and 20% potatoes.

Milk had the highest GWP for all functional units. However, the difference between milk and the other products decreased considerably when GWP per kg was compared with the weighted protein quality index (PQI), due to milk's beneficial amino acid profile and slightly higher protein digestibility. However, its impact was still considerably higher than that of the two plant-based options (Fig. 5.4). As regards land use, the difference between animal and plant-based foods decreased when a protein-based functional unit was used, with milk showing the greatest improvement. As regards ecotoxicity, chicken and pork had considerably higher impacts than ruminant production, as a large share of the feed consists of soy and grain for which pesticide use is much greater than in ley. Plant-based products had lower impacts mainly because less crop needed to be harvested per kg of final product compared with production of animal products, which required 3-10 kg of feed per kg of meat.

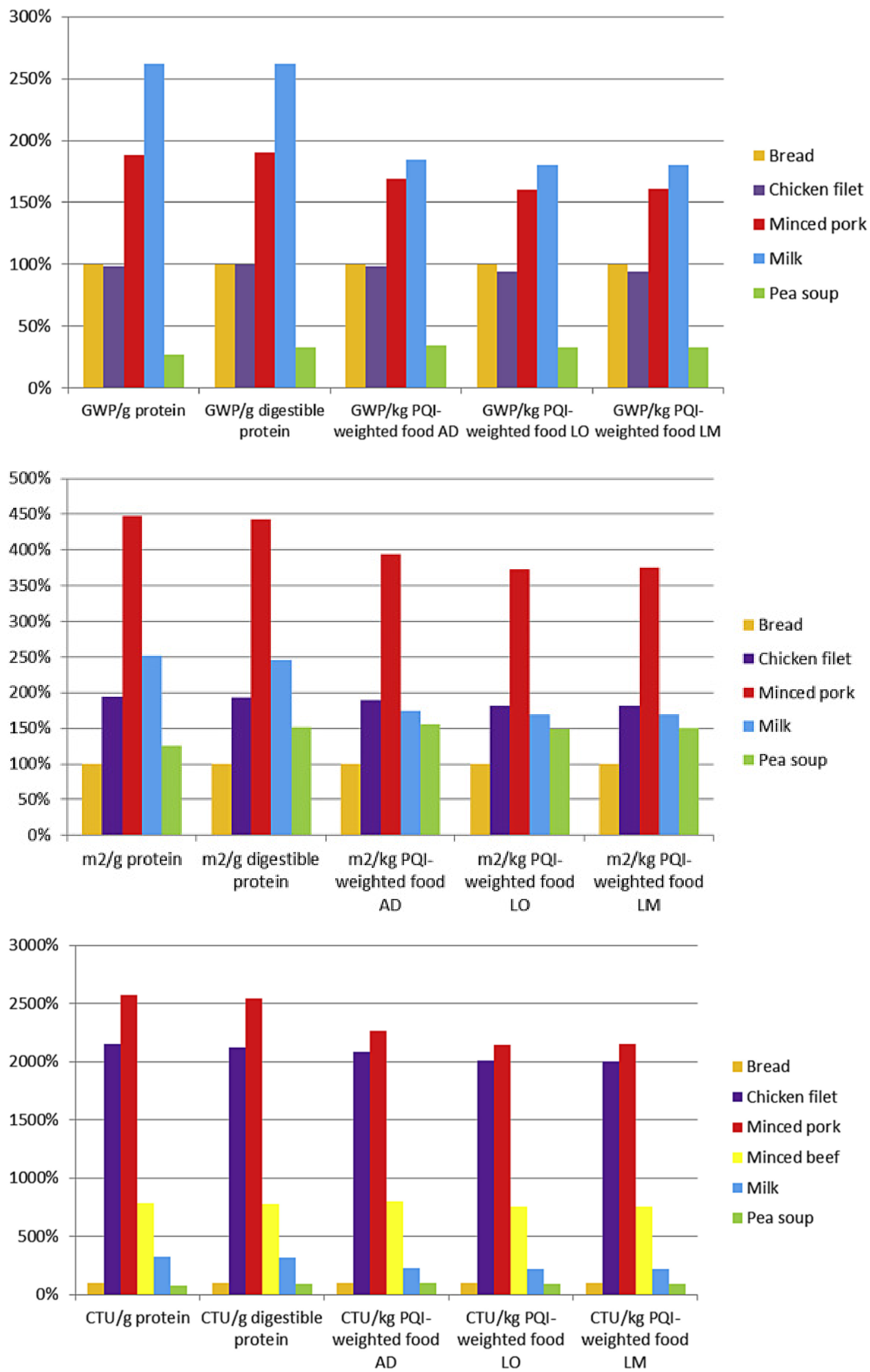

Fig. 5.4. Global warming potential (GWP, top), land use (centre) and ecotoxicity (expressed as comparative toxic units (CTU), bottom) impacts expressed in relation to three different protein-based functional units (g protein, g digestible protein, kg PQI-weighted food), the latter for three dietary contexts (AD=average Swedish diet, LO=lacto-ovo diet, LM=low-meat diet). Bread=100%. From Sonesson et al. (2017).

As mentioned in section 3.4, there are many design decisions that have to be taken into account when creating nutrient density scores, including which nutrients to include (both nutrients to encourage and nutrients to limit), how to weight nutrients (equally as in e.g. the Smedman et al. (2010) study, or considering which nutrients that are a concern in a specific dietary context), whether to cap nutrients for which the food item delivers amounts above recommendations and which algorithm to use for aggregation.

Hence, nutrient density indices can be created in many different ways, which will strongly affect the results (Saarinen et al., 2017). This is one of the limitations with using nutrient density indices for comparing the nutritional quality of foods and diets. It is therefore very important that studies using such scores show, using sensitivity analysis, how the results are affected by the design of the index, which e.g. the Smedman et al. (2010) study failed to do. More elaborate indices, e.g. the protein-related functional unit suggested by Sonesson et al. (2017), may provide valuable information. However, the complexity of such indices makes them more difficult to interpret. In terms of using nutrient density scores, Hallström et al. (2018) summarise the following research needs: inclusion of a wider set of sustainability issues (e.g. biochemical flows or freshwater use), including the dietary context, combining consumption and production perspectives (e.g. distinguishing between different cultivation and livestock systems, as well as process settings and preparation methods), including consumer and acceptability aspects, distinction between populations, further refinement and validation of scores and the application of methods in society.

5.2.2 Comparison in a diet context

Comparing foods on a per product basis has limited value for determining the health outcomes or environmental impact of eating patterns, as it is the total impact of all foods in the diet that determines final outcomes. Increasing numbers of studies have investigated the effect on nutrient intakes, dietary quality and environmental impacts from dietary change, commonly reducing the consumption of animal-based products and replacing it with plant-based foods. The reviews by Hallström et al. (2015) (Fig. 5.5), Aleksandrowicz et al. (2016) (Fig. 5.6) and González-García et al. (2018) provide good overviews of the results from such studies, which in general show considerably lower climate impact and land use from vegetarian or vegan diets. However, there are exceptions; Vieux et al. (2012) found that when some meats were replaced by fruit and vegetables on an iso-caloric basis, no reduction or even an increase in GHG emissions was observed, due to the large amounts of fruit and vegetables needed.

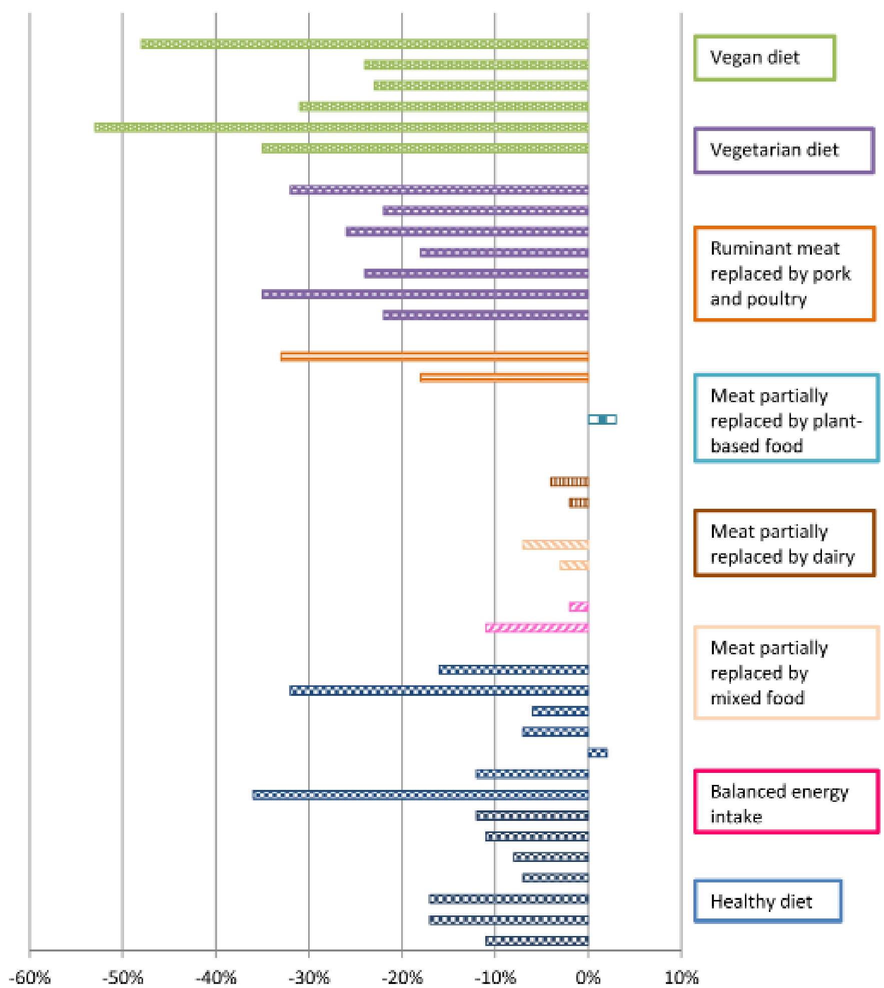

Fig. 5.5. Relative change (%) in greenhouse gas emissions (kg CO_2e per year) brought about by different dietary changes. From Hallström et al. (2015).

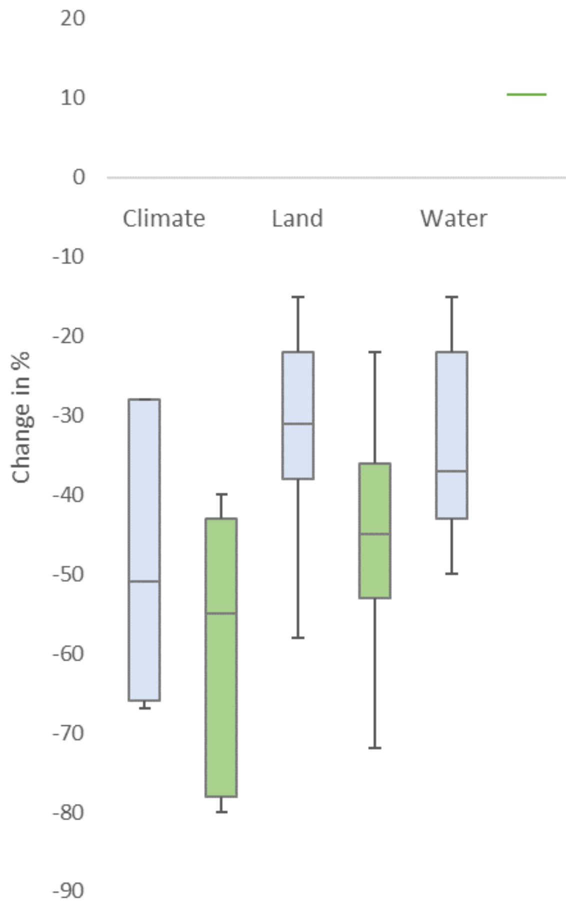

Fig. 5.6. Reduction in climate impact, land use and water use from transitioning a vegetarian diet (blue) and from a vegan diet (green). Based on data from Aleksandrowicz et al. (2016).

Several different approaches for evaluating and designing more healthy and sustainable diets exist (see Mertens et al. (2017) for an overview). Such studies can roughly be categorised into 1) simulation studies, in which different pre-defined changes to diets are evaluated, e.g. a certain reduction in meat consumption or adherence to a certain dietary pattern, and 2) optimisation studies, in which mathematical methods are used to find a diet that meets several goals, typically the fulfilment of nutritional recommendations and lowering of GHG emissions while keeping diets as similar as possible to current diets. We summarise some interesting studies of each type below.

Examples of simulation studies in which both meat and dairy are replaced by plant based foods

Temme et al. (2013) evaluated how a 30% and 100% decrease in meat and dairy, randomly replaced by the same amount (mass) of plant-based dairy and meat-replacing foods, affected land use and nutrient intake of 398 Dutch women aged 19-30 years. Liquid dairy foods were replaced by soy-based dairy alternatives and meat by a vegetarian meat substitute (43%, three times weekly), egg (29%, twice weekly), pulses (14%, once weekly) or tofu/tempeh (14%, once weekly), based on the proportion of these in the current consumption patterns in this group. Animal-based sandwich toppings were replaced by a combination of peanut butter, chocolate nut spread, jam and chocolate sprinkles, based on current consumption. This approach was chosen in order to make the choice of replacement foods as realistic as possible. The results showed that land use decreased from 3.7 to 1.8 m^2 per day when all animal-based foods were replaced, while for a 30% reduction land use was 3.1 m^2 per day. Intake of saturated fatty acids decreased considerably compared with the current consumption in this group (making three times the number of women meet the recommendations), and total iron increased by 2.5 mg per day for 100% replacement and 0.7 mg per day for 30% replacement (from the average 9.5 mg per day in typical current consumption), although most iron was in less bioavailable form. The authors comment on this as follows:

"At baseline, however, about 10 % of the total Fe intake was haem-Fe, whereas in the 100 % scenario all Fe was non-haem. This might be a concern since it is known that non haem-Fe is absorbed less efficiently than haem-Fe. On the other hand, Fe absorption is tightly regulated by Fe status and body storage; if Fe storage is depleted, more Fe is absorbed. Cross-sectional studies suggest that vegetarian women have similar or even higher Fe intakes and similar Hb concentrations than meat-consuming women."

Temme et al. (2015) repeated the evaluation for children and concluded that partial replacement (30%) of meat and dairy by plant-based foods is beneficial for children's health, as intake of saturated fatty acids is lowered, fibre intake is increased and intake of micronutrients is similar. When all animal-based products are replaced, attention is needed to ensure adequate intake of thiamin, vitamin B12 and zinc. The proportion of girls (4-6 years old) with intake below the recommendation was 15% for thiamin, 10% for vitamin B12 and 6% for zinc. A similar study was conducted on Dutch adults (Seves et al., 2017), with similar results (Table 5.10).

Table 5.10. Summary of studies by Temme et al. (2013, 2015) and Seves et al. (2017) in which nutrient intake, land use and greenhouse gas (GHG) emissions (except Temme et al., 2013) were studied for two dietary scenarios: meat and dairy reduced by either 30% or 100%, and replaced with plant-based foods including fortified plant-based meat and 'dairy imitates'. SFA = saturated fatty acids, Fe = iron, Ca = calcium, Zn = zinc

	Subjects	Studied outcomes	Results for 30% reduction in meat and dairy	Results for 100% reduction in meat and dairy
Temme et al. (2013)	398 Dutch women aged 19-30 years	SFA and Fe intakes Land use	SFA down 8% Fe up 7% Land use down 19%.	SFA down 30% Fe up 26% Land use down 51%.
Temme et al. (2015)	1279 Dutch children aged 2-6 years	Nutrient intakes (energy, protein, SFA, fibre, Ca, Fe, Zn, vitamin B12, thiamin) Land use and GHG emissions for meat and dairy and plant-based replacements only	SFA down 9% Fibre up 8% Similar micronutrient content except for B12	SFA down 26% Fibre up 29% Ca, Zn and thiamin down by 5-13%, and vitamin B12 down by 49%. Total Fe up.
Seves et al. (2017)	2012 Dutch adults aged 19-69 years	Nutrient intakes (energy, protein, SFA, monodisacc., fibre, Na, Ca, Fe, Zn, vitamin A, B12 and D, thiamin and riboflavin) Land use GHG emissions	Beneficial for SFA, Na, fibre and vitamin D intakes, neutral for other nutrients. Land use down 14%. GHG emissions down 14%.	SFA down ~35% NA down ~8% Fibre, Fe and vitamin D increased. Zn, thiamin, vitamins A and B12, and probably Ca, were below recommendations. Land use down 41., GHG emissions down 47%.

Examples of studies using optimisation techniques to design more sustainable diets

A recent study worth highlighting is that by Vieux et al. (2018), in which observed diets from five countries (France, UK, Sweden, Italy and Finland) were optimised using linear programming (see section 4.5), with the aim of reducing diet-related GHG emissions while at the same time ensuring nutrient adequacy. One of restrictions initially applied was that total weight of modelled diets could vary between 120% and 80% of the original total weight. When just adjusting diets to achieve nutrient adequacy by replacing items in the category sugar/fat/alcohol with foods from the fruit and vegetables and starchy foods groups, the GHG emissions of the diets increased. Once nutrient adequacy was achieved, stepwise reductions in GHG emissions were modelled (in 10% increments). At 30% reduction, energy coming from dairy products increased for both men and women in Sweden and France, and it increased in men, but decreased in women, in Finland, Italy and the UK. The dairy group also contained 'dairy imitates', but these only constituted a minor part of the consumption. It is unclear why these did not make up a larger part of the diet, but one possible explanation could be that their sugar content made them a less optimal product.

Kramer et al. (2017) used linear programming to optimise diets for Dutch men and women (9-69 years old) based on minimal changes to diets, meeting nutritional constraints and stepwise lowering of environmental impacts (GHG emissions, fossil energy use and land occupation - accounting for approximately 90% of the total ReCiPe score in food products). Fortified soy drink, legumes and fortified meat replacers were included as alternatives to animal-based products. Grams consumed was used as a proxy for popularity; foods for which consumption is high were given a higher penalty for decreased consumption. Fig. 5.7 shows how the amount of different food groups changed for Dutch men as the requirements for environmental impact gradually decreased and how the penalty score increased. At the 'critical point' in terms of the penalty score, the consumption of dairy products was relatively unchanged, but the intake of meat decreased.

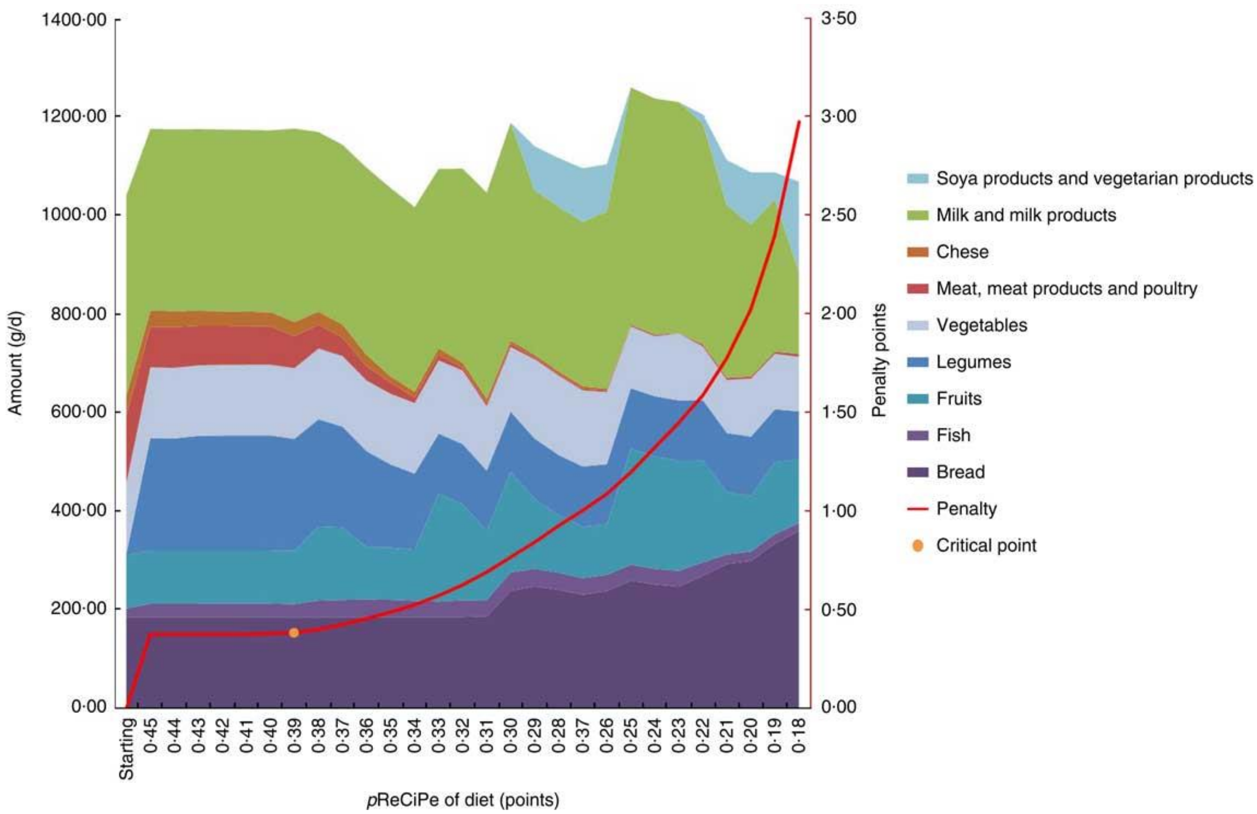

Fig. 5.7. Amounts of food groups and penalty score of different environmental impacts (pReCiPe points) for diets for Dutch men aged 31-50 years. From Kramer et al. (2017).

Studies specifically investigating replacement of dairy

To our knowledge, only a few studies have specifically investigated the effects of substituting dairy partially or completely with plant-based dairy alternatives in a dietary context, i.e. without also reducing meat intake. These include studies by Werner et al. (2014), van Dooren et al. (2014) and Blonk Consultants (2015), as summarised below.

Werner et al. (2014) specifically aimed at investigating the role of dairy in diets in terms of nutritional value and GHG emissions. The starting point was a constructed baseline diet which was in agreement with the Danish dietary guidelines, using foods included in the Danish national dietary survey. For example, to be in line with the Danish recommendations, a fruit and vegetable intake of 600 g was set where 100 g of fruit were taken to comprise 45.3 g apple, 15.6 g pear, 16.4 g orange and 22.7 g banana, reflecting the average fruit intake of the population. The baseline diet included 349.5 g of dairy. Eight dietary scenarios, with different quantities of dairy products in each, were designed, all with the same energy content. Three diet scenarios excluded dairy entirely, one including instead unfortified soy drink instead of milk, one including soft drinks instead of milk and marmalade instead of cheese and the third was a vegan diets in which soy drink and beans replaced animal products. Naturally, the nutritional outcome of the scenario with soft drink and marmalade replacing dairy products was negative and GHG emissions were not decreased. The diet in which soy drink replaced dairy lowered GHG emissions by approximately 20% and the vegan diet lowered them by nearly 50%. Added sugar was above recommendations for the diet in which soy drink was used, while for the vegan diet fat content was below the recommendation. As regards micronutrients, both the soy drink and the vegan diet were below the recommendation for vitamin D (as was the baseline diet) and the soy drink was also below the recommendation for iron (as was the baseline diet). Both the soy drink and the vegan diet were below the recommendations for calcium, iodine and selenium.

van Dooren et al. (2014) investigated the GHG emissions, land use and nutritional quality of diets using 10 different indicators: the amount of fruit and vegetables, total fatty acids, trans-fat, saturated fatty acids, fibre, sugar, salt, fish and the energy content. They applied these to six different diets; current average Dutch, official 'recommended' Dutch, semi-vegetarian, vegetarian, vegan and Mediterranean. In the vegan diet, milk was replaced with calcium-enriched soy drink and meat with pulses, nuts and ready-to-eat meat substitutes (e.g. tofu) and vegetables rich in calcium. The authors highlight that for the vegan diet, products fortified with B12, vitamin D and calcium should be chosen. The Mediterranean diet scored the highest in terms of nutritional quality (122), closely followed by the vegan diet (118), the recommended diet (105), the semi-vegetarian diet (103), the vegetarian diet (100) and the current average Dutch diet (75). The vegan diet scored higher than the vegetarian diet for all nutrition indicators. The GHG emissions of the vegan diet were the lowest of all diets, at 2.7 kg CO_2e per day, which was 34% lower than for the current average diet, while the value for the vegetarian diet was 3.2 kg CO_2e per day (22% lower than for the average Dutch diet).

Blonk Consultants (2015) found little or no environmental benefit in terms of GHG emissions and land use of replacing dairy products with non-dairy foods when using the Optimeal® optimisation program to perform the analysis, while the outcome for meat was significantly different. Optimeal® was used to help investigate sustainable and healthy diets. The starting point was a full diet including a certain amount of dairy. The amount of dairy was varied in steps of 100 g of milk per day (starting from 0 g and going up to 1 kg) and replaced by other foods including vegetables, nuts, fortified soy drinks, eggs and fish. As the amounts of dairy products increased compared with the current diet, the amounts of meat, eggs and nuts were reduced and the amounts of pulses, vegetables and fruit were increased (Meike van de Wouw, Blonk Consultants, personal communication 2018). As the environmental impact of the diet at each optimisation step did not vary greatly, the authors concluded that replacing dairy products with alternative products had little effect on the GHG emissions.

5.2.3 Comparison from a production system perspective

A third perspective to include when comparing dairy and plant-based dairy alternatives is the production perspective, e.g. by including the opportunity cost of land and ecosystem services that grazing cattle provide. This is a highly complex and context-specific question which relies on a large set of assumptions on what would potentially happen to the land. Therefore, few such studies have been performed.

Röös et al. (2015b; 2016a) performed a study for Sweden in which the GHG emissions, eutrophication and acidification potential and ecotoxicity impacts from dairy production were compared with those from oat drink production from a farm perspective. The starting point was a fictional farm of 336 ha (49 ha of pasture and 287 ha of arable land - the same proportions of pasture and arable land as in Sweden as a whole) with 100 dairy cows, which served as a reference scenario. Eight alternative scenarios in which the production of dairy milk on the farm was replaced with production of oat drink (based on mass) on the same farm were analysed (Fig. 5.8). Land 'spared' in the oat drink scenarios was used to produce bioenergy in the form of biogas from grass-clover leys and the surplus energy was assumed to be exported from the farm, where it could replace diesel. In all scenarios, the same amount of land was used and grazing animals were assumed to be kept on semi-natural pastures. Hence, the study compared the environmental impacts assuming similar land use for both dairy and oat drink production.

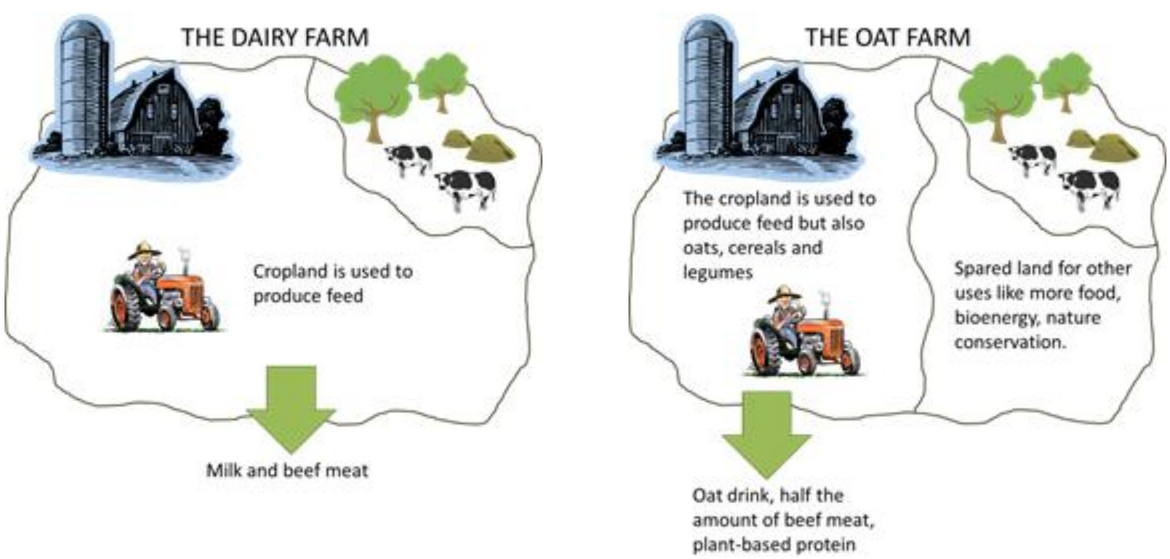

Fig. 5.8. Schematic illustration of a study comparing the environmental impact from the production of either milk or oat drink on a fictional farm in Sweden. In both cases, the same area of semi-natural grassland is grazed and the same amount of cropland is used. From Röös et al. (2015b).

In scenario 1, the beef produced in the reference scenario from the dairy cows and their offspring was replaced with beef from suckler herds. In scenario 2, dairy beef was replaced with chicken and in scenario 3 with a combination of cereals and grain legumes. In scenario 4, a combination of dairy milk, oat drink, beef meat and vegetable protein was produced. The other four scenarios (HP1, HP2, HP3 and HP4) corresponded to scenarios 1-4, with the only difference being that additional plant protein in the form of cereals and grain legumes was grown on the farm, so that it produced as much total protein as in the reference scenario.

The results showed that the climate impact was lower for all eight alternative scenarios compared with the reference scenario, due in particular to reduced methane emissions from ruminants (Fig. 5.9, left). When the substitution effect of biogas replacing diesel in society at large was considered, the benefit to the climate from producing oat drink instead of milk was substantial. Even in scenarios producing the same amount of beef as in the reference case (scenarios 1 and HP1), the GHG emissions were lower due to lower methane emissions from suckler cows compared with dairy cows and less need for feed. However, the eutrophication potential was somewhat higher in the oat drink scenarios and the acidification potential was substantially higher in scenarios 1-4. This was a consequence of the higher amounts of spared land in these scenarios, which gave more biogas production and in turn more nitrogen-rich digestate as a by-product from this production. Handling of digestate can result in considerable ammonia losses during storage and spreading. The substitution effect of biogas replacing diesel in society was found to be very small for eutrophication and acidification potential, since it was assumed that emissions of eutrophying and acidifying substances were about the same for biogas and diesel.

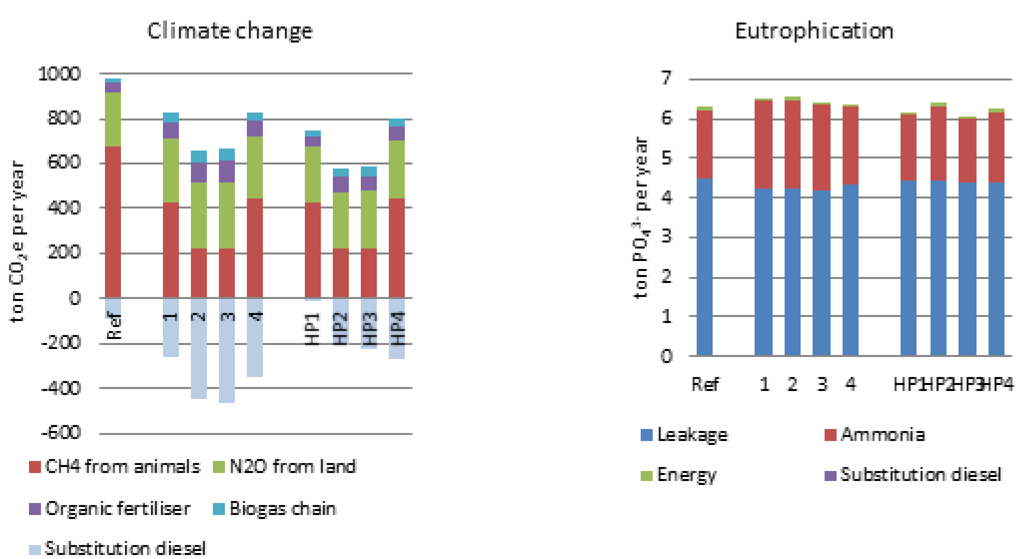

Fig. 5.9 Impacts on climate change and eutrophication of a Swedish dairy farm and of eight different scenarios producing oat drink instead of dairy milk on the farm. In all scenarios, the same amount of semi-natural pasture was grazed and the same amount of arable land was used. From Röös et al. (2016b).

6. Conclusions and further research needs

Assessing the sustainability of diets is highly complex, due to the multitude of issues that can be considered crucial for the sustainability of human eating habits and food systems (health, different environmental and social issues, use of antibiotics, animal welfare etc.). Individual research fields have supplied knowledge about parts of this complex picture. For example, the field of diet-related health research is vast and has identified overarching principles of healthy eating that most researchers agree upon (diet with plant-based foods, limited intake of salt, sugars and red and processed meat, use of whole grain and unsaturated fats, use of low-fat dairy). Studies on the environmental impact of food have shown that animal-based products in general have higher negative impacts than plant-based foods. Research on animal welfare has provided knowledge on how different production systems affect animal health and wellbeing, and so on. However, these guiding principles have to be broken down even further to be applicable in answering questions on the appropriateness of different diets for different groups and have to handled alongside aspects such as diet acceptability and what can realistically be changed. Promising initial attempts have been made to gather several aspects of sustainable diets into indicator-based frameworks, in order to provide a way to consider a multitude of issues and their trade-offs in different types of decision making. Much more work is needed in this area to make indicators and frameworks for assessing the sustainability of diets more robust, transparent, relevant and useful. To enable constructive discussions and sound decision making, such frameworks has to, as far as possible, show what are scientific 'facts' and what are normative decisions (choice of indicators, thresholds and weighting methods). Complexity will inevitably rise with the number of issues included, so trade-offs between comprehensiveness and comprehension have to be managed.

As regards the role of dairy products and plant-based dairy alternatives in sustainable diets, research shows some clear positive health effects for dairy products and for fortified soy-based products. For other plant-based dairy alternatives, there is little or no literature on their long-term health effects (although there has been some research on the raw material used for some products, e.g. oats). Hence, epidemiological studies on these products are urgently needed. However, it will take a long time before there is any solid evidence on this, as consumption of these products has only begun recently, and therefore information on consumption of these products is not available in existing cohorts. Unfortunately, there is no time to await such evidence, as environmental issues need urgent attention.

Regarding the environmental impacts of dairy products and their plant-based alternatives, the current literature indicates that the climate impact of dairy milk from Western industrialised systems (a little over 1 kg CO_2e per kg milk on average, but with large variation) is twice or three times higher than for plant-based drinks. However, this comparison rests on somewhat shaky grounds, as existing studies on plant-based alternatives are not peer-reviewed and as different studies have used different methodological choices (e.g. in terms of allocation methods). In order to draw solid conclusions and better understand the drivers behind differences in carbon footprint, dairy and plant-based drinks should be compared within the same study, using the same methodological choices and applying comprehensive sensitivity analysis. For other environmental impacts, the data are very limited. The few studies that exist (on water use, ecotoxicity, nitrogen footprint, eutrophication and acidification potential and negative biodiversity impacts) indicate higher impact for milk than for most plant-based dairy alternatives, but the data are too limited to allow any general conclusions to be drawn on the average magnitude of the differences and the impacts are also highly site- and context-specific. An important exception to the higher negative impacts of dairy milk is the positive contribution of grazing animals to some semi-natural pastures, which promotes biodiversity conservation in those sites, contributes to landscape aesthetics and acknowledges the ability of animals, especially ruminants, to upgrade low-value biomass streams into nutritious foods for humans, an aspect that conventional LCA studies have not been able to capture.

Comparisons on a per kg basis might give different results if the health effects of the different products were taken into account. To date, this has been done only in a few studies and using nutrient density indices, which inevitably involves a range of normative decisions that strongly influence the results. More research is needed in this area, applying different nutrient indices to a range of plant-based dairy alternatives in order to evaluate whether a general pattern can be distinguished or whether the results are dependent on the design of the nutrient index. If plant-based alternatives are fortified to resemble dairy milk, they score very similarly to dairy milk in terms of the nutrient density, and the environmental advantage of plant-based alternatives will remain. However, it is unclear whether the nutrient content reached by fortification is 'the same' as 'natural' occurrence of nutrients in the diet. This is another question in need of more discussion and investigation. In addition, ways are needed to include health effects, rather than nutritional content, in this comparison, including bioavailability, the 'matrix-effect', nutrient interactions and presence of active compounds.

Ultimately, comparing products on a product-by-product basis, whether per kg product or using nutrient profiling provides, only provides limited information, as the nutritional benefit depends on the diet in which the product is placed and the total environmental impact of the product depends on how much of the product is included in the diet and how the substitution affects other food categories. The limited existing research on replacement of dairy products with different types of plant-based dairy alternatives indicates that the benefits of these products are context-specific. More modelling studies are needed to test a broad set of consequences of including either dairy products or a range of different plant-based alternatives, or combinations of these, in different dietary contexts for different types of consumers. To make these as relevant as possible, more research is needed on how people actually, rather than potentially, change their eating patterns when aiming for a less environmentally damaging and healthier diet.

Finally, what people eat naturally affects what is produced, which in turn affects landscapes and rural societies. Such socio-economic effects are highly challenging to capture in conventional indicators, and therefore methodologies that enable inclusion of socio-economic issues also need to be developed.

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Appendix A. Frameworks for sustainable development

Fig. A1 shows the updated version of the Planetary Boundaries framework based around nine critical processes that regulate the functioning of the Earth systems (Rockström et al., 2009; Steffen et al., 2015). By combining scientific understanding of the processes regulating the Earth's functioning with the precautionary principle, the framework identifies different levels of anthropogenic activities for which the risk of destabilisation of the Earth's systems is likely to remain low - called the 'safe operating space of humanity'. The red zone represent a dangerous level for the given process, where there is a high risk of serious impacts on earth systems. The zone in between the safe operating safe and the dangerous level is regarded as a zone of uncertainty, which still means an increased risk of serious impacts. At the 'safe' end of the zone of uncertainty, current scientific knowledge suggests that there is very low probability of crossing a critical threshold or substantially destroying the resilience of the earth's system. Beyond the 'danger' end of the zone of uncertainty, current knowledge suggests a much higher probability of a change to the functioning of the Earth's system that could be harmful for human societies. Application of the precautionary principle means that the Planetary Boundary is set at the 'safe' end of the zone of uncertainty. This does not mean that transgressing a boundary will instantly lead to an unwanted outcome, but rather that the further the boundary is transgressed, the higher the risk of potential shifts, destabilised processes, erosion of resilience with fewer opportunities to prepare for such changes.

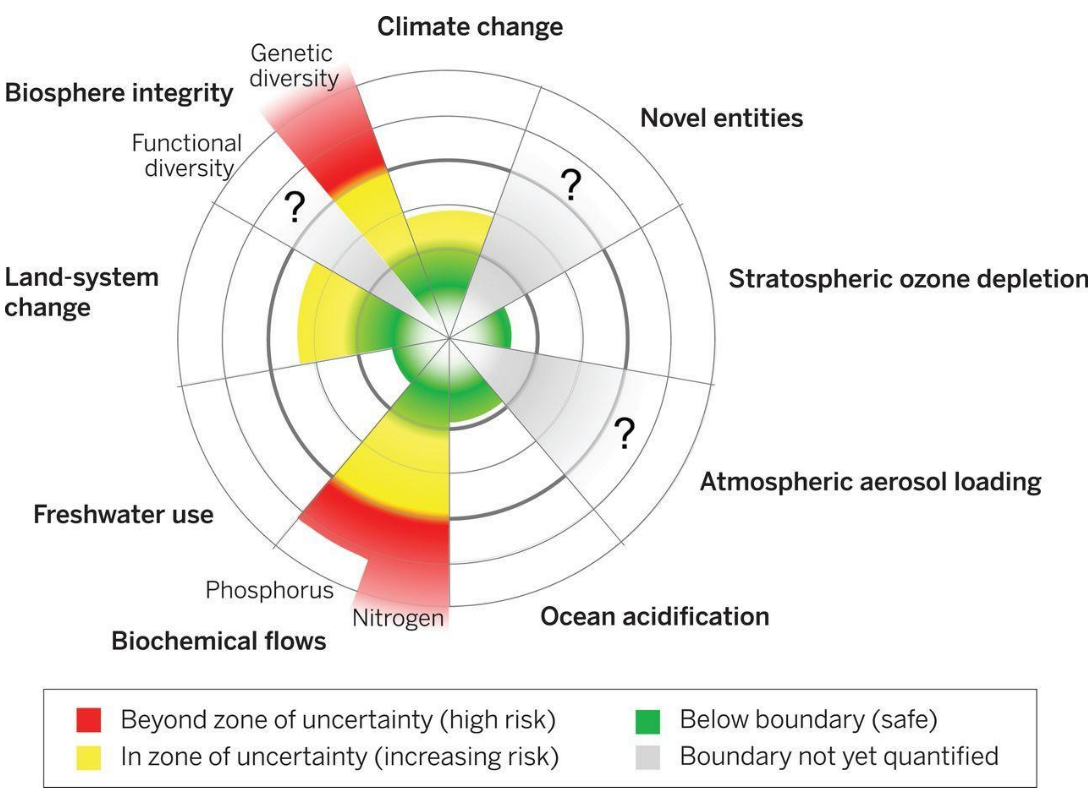

Fig. A1. The planetary boundaries defined by Steffen et al. (2015). Question marks represent processes for which global-level boundaries cannot yet be quantified (atmospheric aerosol loading, novel entities, the functional role of biosphere integrity). From [Steffen W, Richardson K, Rockström J, Cornell SE, Fetzer I, Bennett EM, et al. (2015) Planetary boundaries: guiding human development on a changing planet. Science 347(6223):1259855]. Reprinted with permission from AAAS.

Fig. A2 shows the 'Oxfam doughnut' created by Raworth (2012). This concept combines the Planetary Boundaries established by Rockström et al. (2009), here called the 'environmental ceiling' by Raworth (2012), with a 'social foundation' based on different governments' priorities in terms of sustainable development. These include 11 social endpoints, which can be grouped into three clusters, focused on enabling people to be:

- Well: through food security, adequate income, improved water and sanitation, and health care
- Productive: through education, decent work, modern energy services and resilience to shocks
- Empowered: through gender equality, social equity and having a political voice.

The 'safe and just space for humanity' arises between this social foundation and the limitations on economic activities imposed by the environmental ceiling.

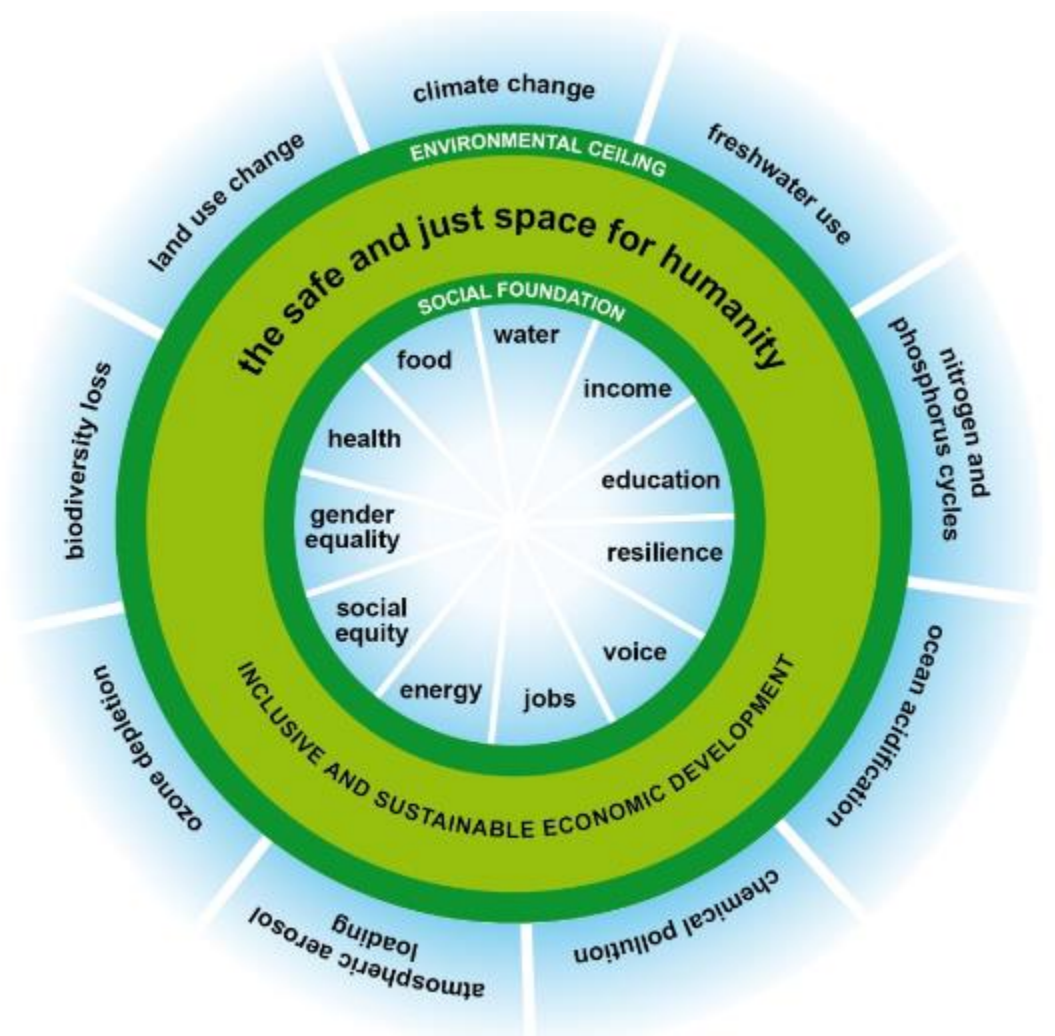

Fig. A2. A framework for incorporating environmental and social boundaries for human development. From Raworth (2012).

A framework developed by Whitmee et al. (2015) shows how the proposed UN Sustainable Development Goals (SDGs) representing human wellbeing (inner circle) are dependent on those that provide the enabling infrastructure for development (the first ring) and the supporting natural systems (the outer ring) (Fig. A3). The framework identifies three categories of challenges that have to be addressed to maintain and enhance human health in the face of increasingly harmful environmental trends: i) Conceptual failure, such as an over-reliance on gross domestic product as a measure of human progress. This is a failure since it does not account for future health and environmental harms over present-day gains, and the disproportionate effect of the harms on the poor and those in developing nations. ii) Failures of knowledge, such as the failure to address social and environmental drivers of ill-health, and a historical lack of transdisciplinary research and funding, together with an unwillingness or inability to deal with the uncertainty within decision-making frameworks. iii) Implementation failures, such as how governments and institutions delay recognition and responses to threats, especially when faced with uncertainties, with failure to pool common resources and time lags between action and effect. The proposed framework also suggests a need for strong governance to ensure that infrastructure-related goals are not achieved at the expense of those supporting natural systems.

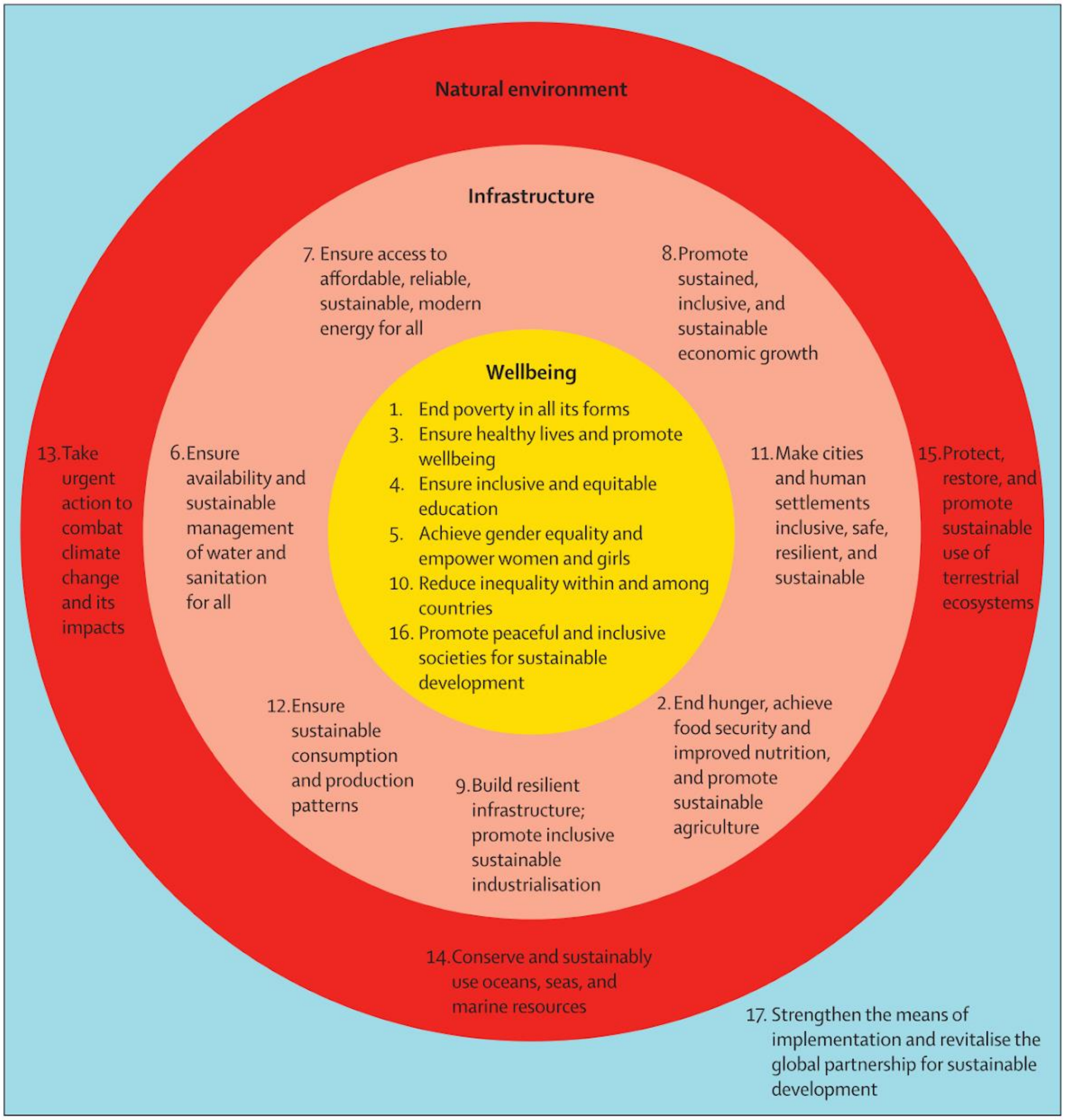

Fig. A3. Framework for examining interactions between Sustainable Development Goals 1-17. From Whitmee et al. (2015).

Broman and Robért (2017) present a framework for strategic sustainable development as a five-level model, which is shown in Table A1.

Table A1. Summary of the five-level model of framework for strategic sustainable development.

Level	**Description**
1. System	The system level includes principles for the functioning of the global system, i.e. the human society within the biosphere, and our knowledge with regard to the planetary and the human condition.
2. Success	The success level includes the definition of the sustainability vision. The framework for strategic sustainable development requires any vision to be framed by basic sustainability principles.
3. Strategic guidelines	The strategic guidelines level includes guidelines for how to approach the principle-framed vision strategically.
4. Actions	The actions level includes the concrete actions that have been prioritised by the specific organisation into a strategic plan, using the strategic guidelines and the vision to inspire, inform, and scrutinise the possible actions.
5. Tools	The tools level includes methods, tools and other forms of support that are often required for decision making, monitoring and disclosures of the actions to ensure they are chosen in line with the strategic guidelines to arrive step-by-step at the defined success in the system. Examples in the sustainability context include modelling, simulation, life cycle assessment, management systems, indicators etc.

In order to explain, formulate and visualise the challenges ahead in sustainable development, Broman and Robért use the metaphor of a funnel (Fig. A4). The detrimental effects that human society have on the planet are shown by a narrowing of the funnel; as the cross-section of the funnel decreases, humanity's potential to fulfil its needs becomes more difficult to achieve, in terms of social, economic and ecological sustainability. The wall of the funnel represents the systematic changes that will occur when our civilisations 'hit the wall'; at this point we will have no choice but to adapt to the current situation. The slight opening at the end of the funnel represents the hope of restoring some of the lost potential through restorative actions and increased freedom and prosperity for future generations.

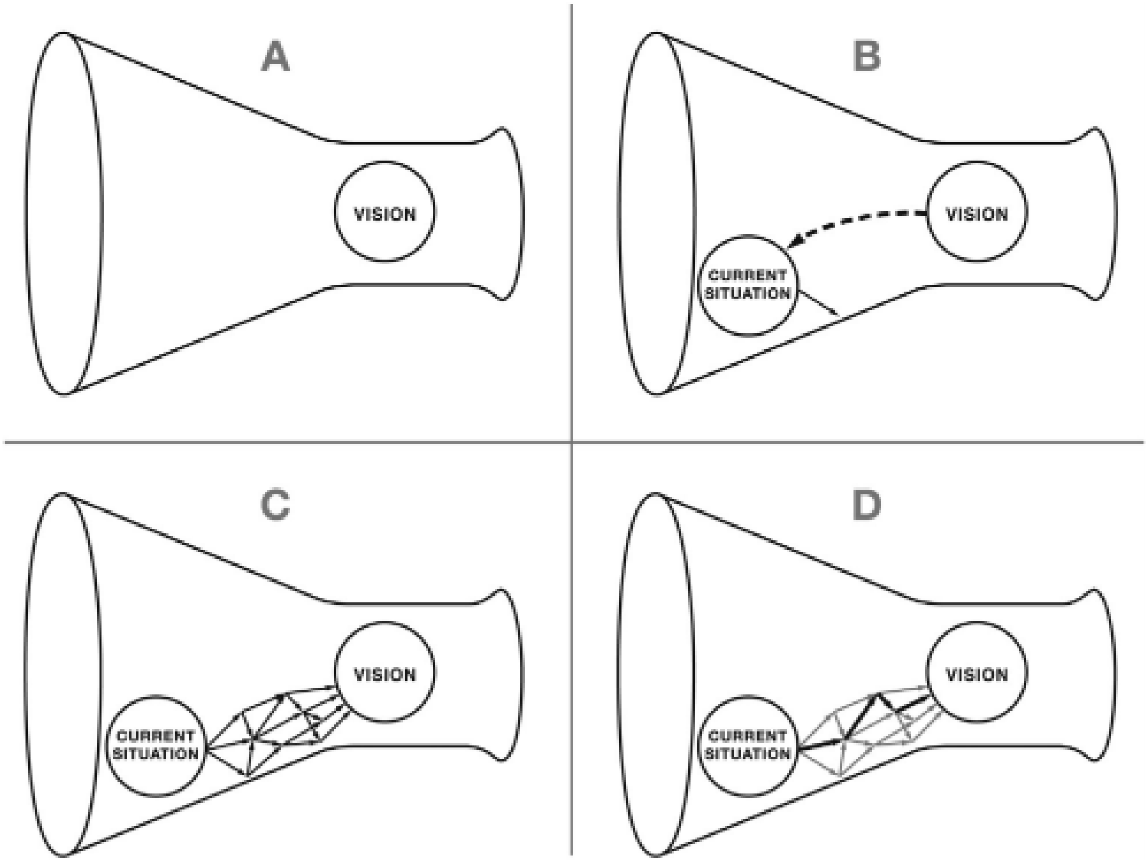

Fig. A4. Funnel metaphor presented by Broman and Robért (2017) to describe the sustainability challenges ahead. A: a sustainability vision is captured. B: the current challenges and assets in relation to the vision are captured. C: possible steps towards the vision are captured. D: steps A-C are prioritised into a strategic plan.

Appendix B. Conceptual frameworks for food systems

Several authors provide conceptual frameworks for foods systems. Here we present a few examples.

A visual representation of the conceptual framework of a food system according the High Level Panel of Experts on Food Security and Nutrition (HLPE, 2017) is presented in Fig. B1. As can be seen, the diet is just one part of the food system as a whole. However, diets interact with many components and activities in the food system more or less directly. For example, diets directly influence consumer health, as 'dietary factors' is a major contributor to declining life expectancy (Forouzanfar et al., 2015).

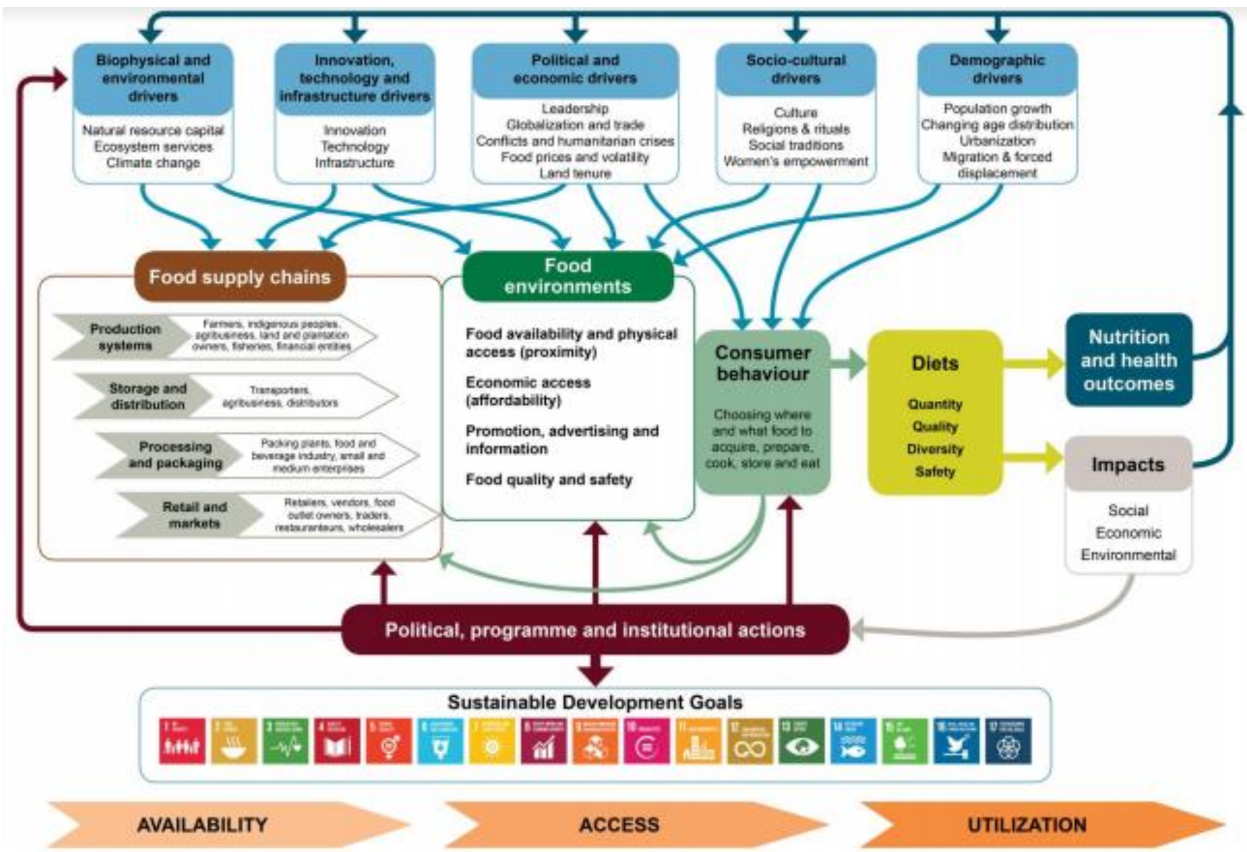

Fig. B1. Conceptual framework of food systems developed by the High Level Panel of Experts on Food Security and Nutrition (HLPE, 2017).

There is also a rather short pathway between diets and the environmental impact from food production. Even if some environmental dimensions are difficult to assess and couple to individual food products, the link between diets and its impact on the environment is strong for other aspects, e.g. emissions of GHG. Diets also impact and are impacted by socio-economic activities and components. However, the causal pathway for these is associated with a higher degree of uncertainty and some outcomes are also to a large extent determined by other factors than explicitly the type of foods in diets. For example, social factors such as working conditions and the fair distribution of food are to a large extent determined by factors independent of the type of diets. They are more a result of e.g. regulations and public support systems to vulnerable groups in society.

Furthermore, the HLPE defines a sustainable food system as:

"a food system that ensures food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition of future generations are not compromised".

Sustainability aspects can be evaluated on food systems as a whole or on different parts of food systems, e.g. farms, production systems, food commodities, food products, meals or diets, depending on the purpose of the study. For example, if the purpose of a study is to compare the environmental impact of the production of pig meat using either rapeseed cake or soybean meal as a protein source, comparing the production of 1 kg of pig meat at the farm level is an appropriate scope. If the purpose is to evaluate e.g. the environmental impacts of diets based on local food versus globally traded foods, or to compare current dietary patterns with alternative diets (e.g. recommended diets), it is necessary to assess the whole diet. Fig. B2, taken from Heller et al. (2013), illustrates in part how the unit of assessment depends on the goal and scope of the study.

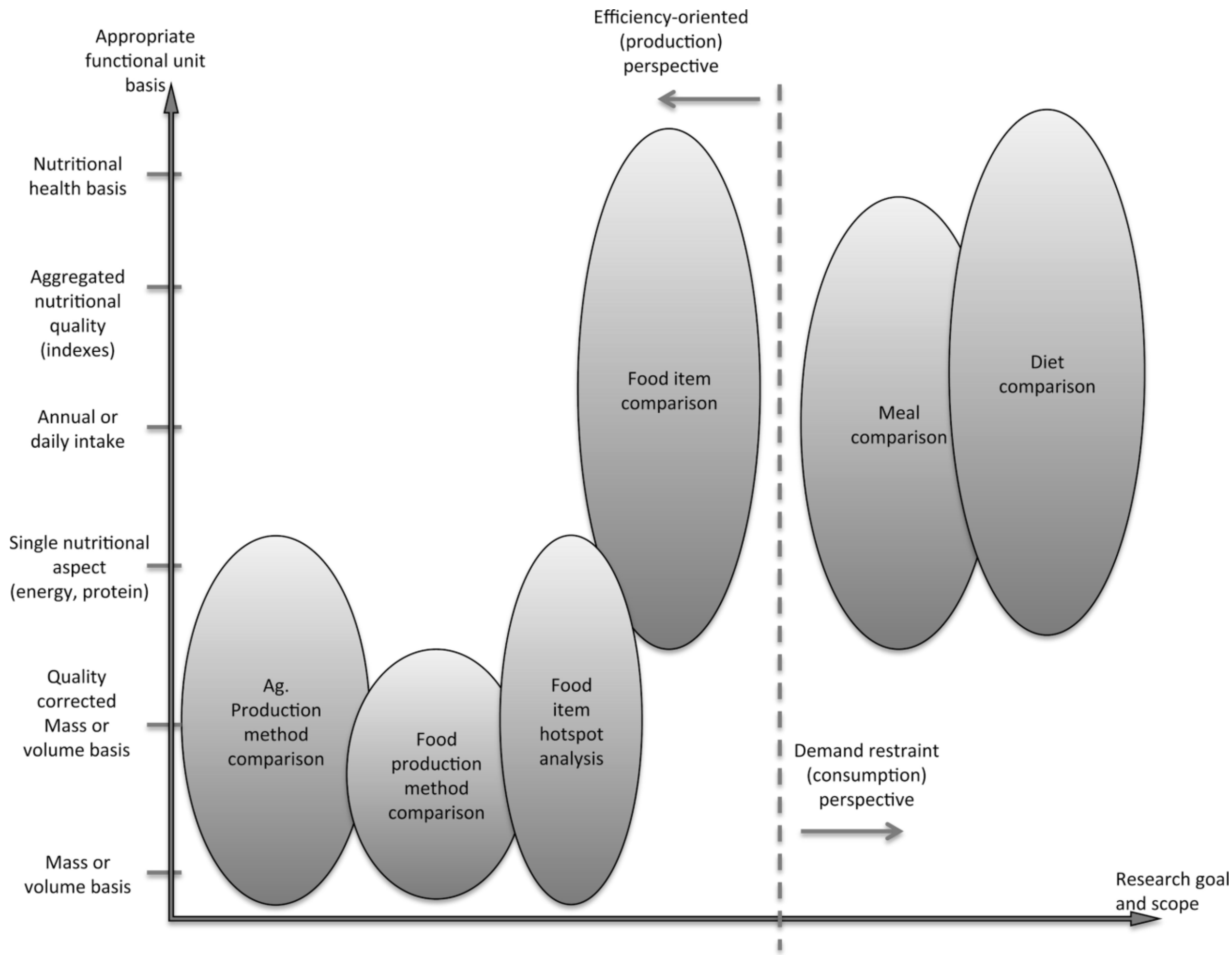

Fig. B2. Visual representation of appropriate units for evaluating the sustainability of agriculture, food and diets depending on the scope of the study. Reprinted with permission from (Heller MC, Keoleian GA, Willett WC. Toward a Life Cycle-Based, Diet-level Framework for Food Environmental Impact and Nutritional Quality Assessment: A Critical Review. Environmental Science & Technology. 2013 Nov 19;47(22):12632–47). Copyright 2018 American Chemical Society.

Horton et al. (2016) provide a ‘generic agri-food ecosystem template’ with four components: 1) the ecosystem, 2) key actors and external factors, 3) food loss and waste and 4) the environmental and health penalties (Fig. B3). The orange lines represent feedback pathways, which should be interpreted as damage affecting ecosystems and human health and the public (people) affecting external factors, such as governments and NGOs.

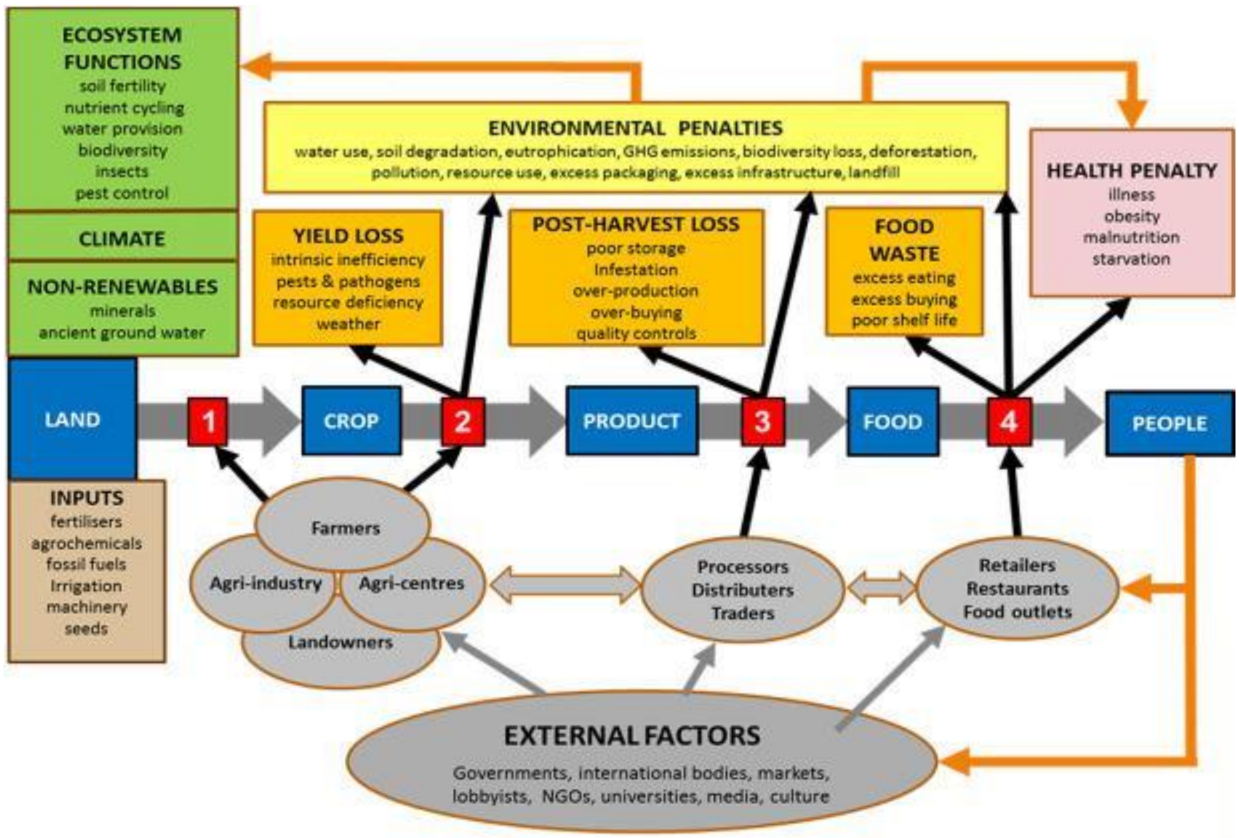

Fig. B3. A generic agri-food ecosystem template with its relevant components and interactions. From Horton et al. (2016).

Kanter et al. (2015) present a visual representation of the links between agriculture, the food system, nutrition and public health (Fig. B4). In that study, 'Nutritional outcomes' were defined as the following: undernutrition in terms of total energy intake, micronutrient deficiencies or low-weight-or height-for-age, and overweight and obesity. 'Agricultural and food policies' were defined as: domestic and international policies, and policy-related programmes, private and public, including trade policies, with some form of agriculture or food system impact.

The framework conceptualises the key influences of agriculture and food systems on nutrition and public health, while remaining relevant to a range of contexts (e.g. countries with different income levels and rural and urban settings). The framework was designed as a guide for use by policymakers.

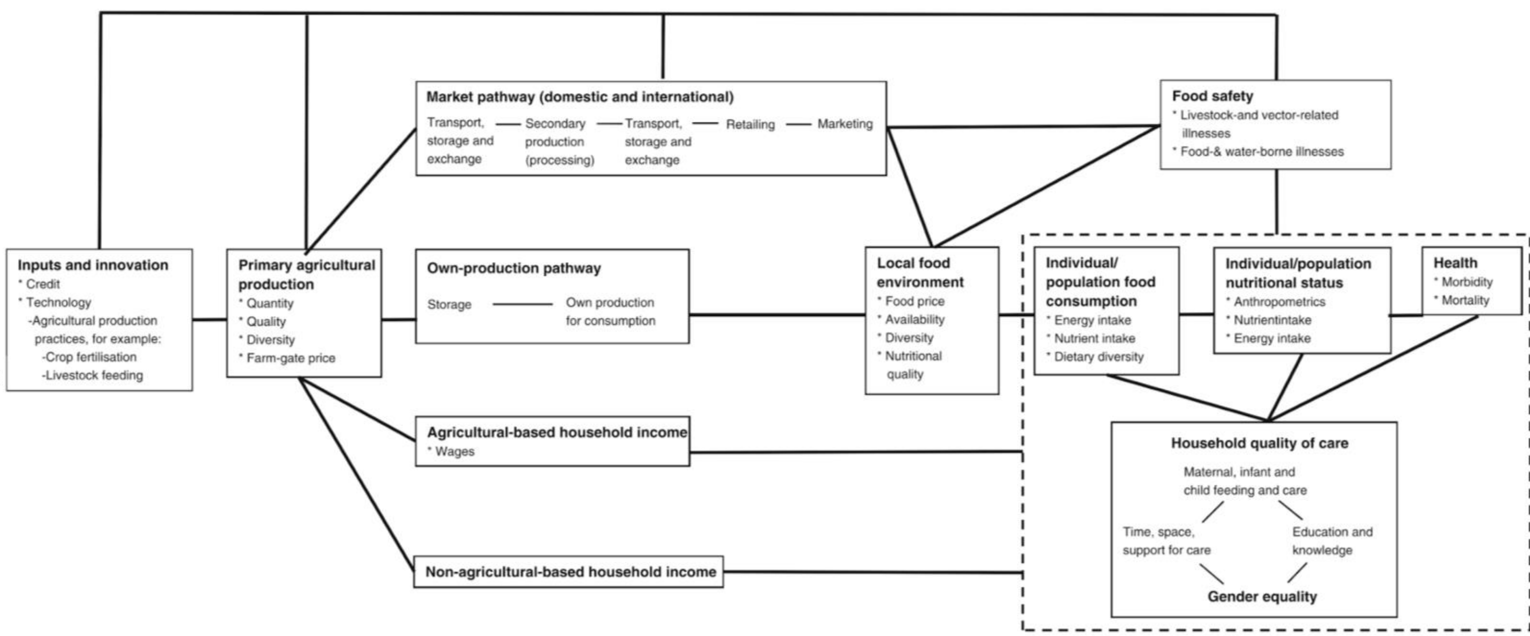

Fig. B4. A visual representation of the links between agriculture, the food system, nutrition and public health. From Kanter et al. (2015).

Appendix C. More on metrics and indicators

C1. Indicator selection and development

Indicator selection, development and evaluation is a whole research field of its own and several authors have suggested methods and requirements for this. Here we provide some examples.

According to Bossel (1999), the necessary requirements for finding relevant indicators for sustainable development include:

- The indicators must represent all important concerns: an ad hoc collection of indicators that just seem relevant is not adequate. A more systematic approach must look at the interaction of systems and their environment.
- The number of indicators should be as small as possible, but not smaller than necessary. That is, the indicator set must be comprehensive and compact, covering all relevant aspects.
- The process of finding an indicator set must be participatory, to ensure that the set encompasses the visions and values of the community or region for which it is developed.
- Indicators must be clearly defined, reproducible, unambiguous, understandable and practical. They must reflect the interests and views of different stakeholders.
- From a look at these indicators, it must be possible to deduce the viability and sustainability of current developments, and to compare with alternative development paths.
- A framework, a process and criteria for finding an adequate set of indicators of sustainable development are needed.

Like Bossel (1999), Hák et al. (2016), who discuss indicator selection for the Sustainable Development Goals, also call for a systematic approach for indicator development, especially the need to start from a theoretical framework of the concept one is assessing rather than ad-hoc gathering indicators guided by e.g. data availability (see Fig. C1 for an example). They also call for a "*...combination of top-down and bottom-up approaches, in which indicators are formalised (defined, constructed and assessed) by measurement experts but their choice depends on political and social preferences...*".

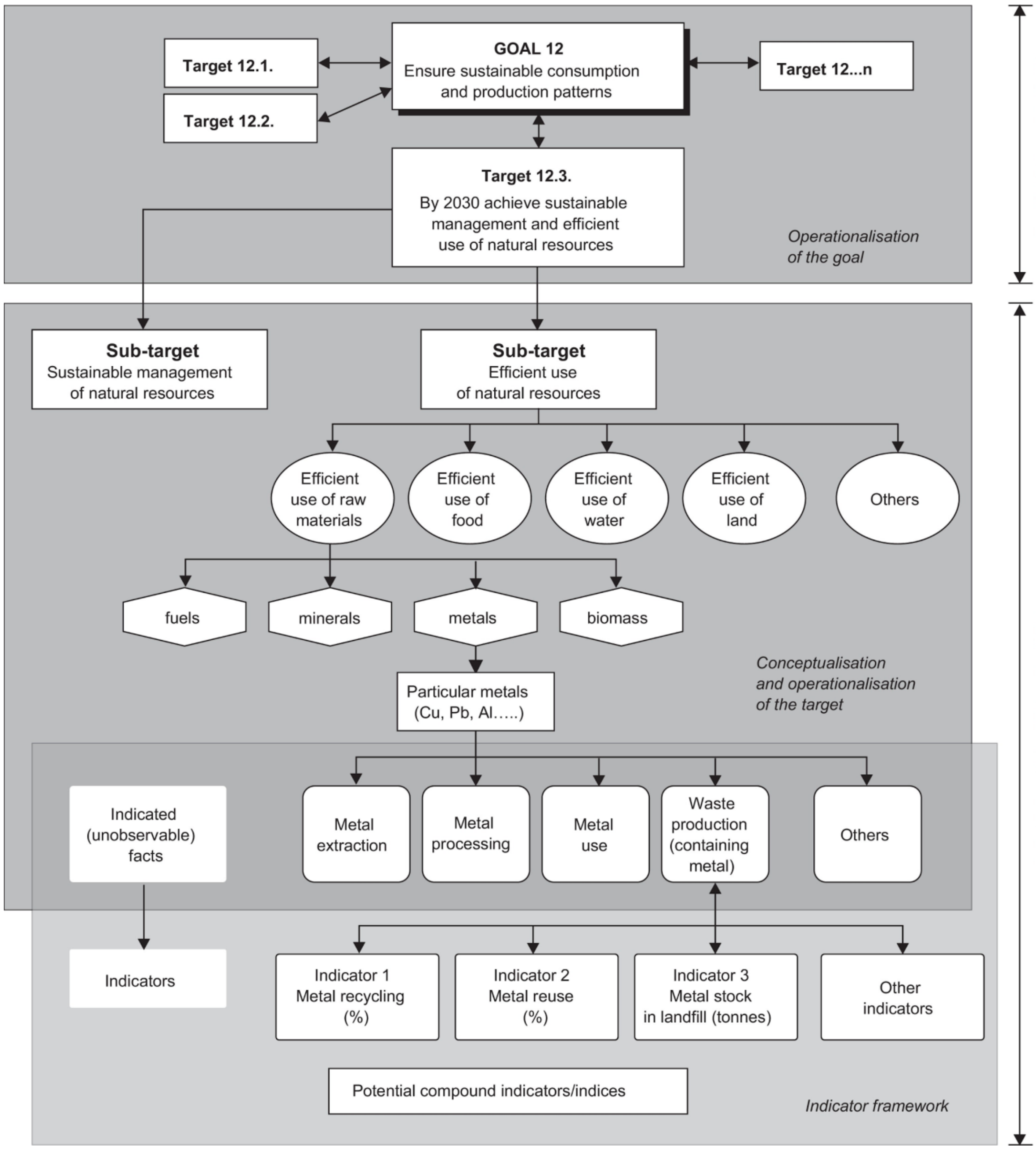

Fig. C1. Indicators should be developed within a conceptual framework starting from the goal or target to be reached and developing indicators that relate to these. From Hák et al. (2016).

Mineur (2007) also provides a set of characteristics that are desired for sustainability indicators, divided into two types; scientific and functional (Table C1). Scientific criteria aim to guarantee the scientific approach with high validity and methodological legitimacy. Functional criteria describe how useful indicators are in a context of politics and policy, where availability of data is one important functional criterion. It is preferable that indicators are both functional and scientific, even though that might not always be the case.

Table C1. Desired characteristics of sustainability indicators. From Mineur (2007)

Scientific	**Functional**
Sensitivity Sensitive to changes	**Simplicity** Easy to use
Quantification Possible to quantify	**Policy relevant** Support prioritised policies and issues
Measurable According to standardized methods	**Available** Use available data
Verifiable Possible to verify by third party	**Timeliness** Able to be produced in reasonable and appropriate time-scale
Clear in value Show a clear direction of possible and negative values	**Few** Manageable to handle
Clear in content Measure what they intend to measure	**Comparable** Serve as benchmarking tool
Appropriate in scale Not over- or under-aggregated	**Feasible** Realistic to measure
Objective Independent of assumptions	**Understandable** Possible to understand by all stakeholders
Changeable Possible to influence	**Democratic** People should have input to indicators choice and have access to results
Comprehensive Embraces all aspects of the issue	**Participatory** Include stakeholders in the measurement process

Moller and MacLeod (2013) provide a review of indicators and measures for sustainability assessments (Table C2 and C3). Those authors try to identify and present issues that balance between practicality and complexity. The report was created to support the development of the New Zealand Sustainability Dashboard, an online sustainability assessment and reporting tool for the country's primary industry sectors. The design roadmap is based upon three basic questions that need to be answered: (1) Why monitor? (2) What to monitor? and (3) How to monitor? The last question identifies the specific measures and elements used to quantify the indicators.

Table C2. Possible criteria for selecting individual agricultural sustainability indicators. From Moller and MacLeod (2013)

Criterion	Description
Sustainability relevance	Indicators should measure key properties of the environment, economy, society or governance that affect sustainability (e.g. state, pressure, response, use or capability)
Clearly defined and standardized	Indicators must be based on clearly defined, verifiable and scientifically acceptable data collected using standardised methods, so that they can be reliably repeated and compared against each other
Easily communicated and understood	Easily communicated and understood
Broad acceptance	The strength of an indicator depends on its broad acceptance by major stakeholders (e.g. growers, policy-makers, scientists, customers)
Affordable measurement	Affordable measurement increases participation and regularity of monitoring or broadens the scope of what can be measured for overall sustainability assessment
Performance rather than practice based	It is better to measure actual performance and outcomes rather than just practices that are expected to promote sustainability and resilience
Sensitivity	Indicators should be sensitive (change immediately and a lot if agricultural system status changes). This helps detect trends or breaches of thresholds within the time frames and on the scales that are relevant to the management decisions, and before it is too late to correct any problems
Quantification	Indicators should be fully quantified whenever practicable. Counts and continuous variables (interval and ratio scales) are more favoured than ranks (ordinal scales) or 'yes/no' scores (binary); any form of quantification is preferable to a fully qualitative assessment
Specificity for interpretability	Indicators should be affected only by a few key drivers (risks, opportunities, causes) of sustainability, rather than being affected by many things (local context, multiple stressors etc.) in order for any change in the indicator to be interpretable for sustainability
High precision and statistical power	Indicators must have sufficient precision and accuracy and sufficiently low natural variance for monitoring to detect trends and probability that some limit or threshold has been breached
Capacity to upscale	Indicators should be designed and measured in a way that allows their aggregation at multiple spatial and temporal scales for different purposes

Table C3. Possible criteria for balancing the collective set of indicators for agricultural sustainability assessment. From Moller and MacLeod (2013).

Criterion	Description
Participatory co-development	Indicator sets and frameworks that are co-designed by key stakeholders are more likely to be relevant, trusted, practical, heeded and used for learning
Wide scope and integration	The framework and indicator sets must cover and cross-link multiple dimensions of sustainability and values encompassing environment, economics, social and governance dimensions
Linked to targets/thresholds	Indicators should be linked to realisable, action-oriented, measurable and time-delimited targets or critical thresholds of risk, performance or best professional practice
Transparency and accessibility	Datasets that are accessible to all stakeholders (including the public) and explain assumptions, uncertainty and sources are more likely to be trusted and used
Policy relevant and meaningful	Indicators should send a clear message and provide information at an appropriate level for policy and management decision-making by assessing changes in the status of and risks to agricultural sustainability

Just enough indicators	The fewer the indicators, the better, provided the critical determinants of sustainability have been covered. Having just enough indicators will result in more participation, improved accuracy in reporting and clearer communication of the overall picture to farmers, policymakers and the public
Mix of generalised and specific	Indicator sets must include enough general indicators to allow cross-comparison between agricultural sectors, regions, countries and diverse social-ecological systems. However, some highly specific and locally grounded indicators must be included to guide fine-grained management adjustments that are especially relevant to one sector or region/country
Balance of current and future	Monitoring is part of risk management, so it must inform current options and drivers while preparing actors for future turbulence (shocks and drivers). At least some of the indicators and measurements should monitor potential new threats and opportunities just over the horizon
Explanatory and context info	Management guidance is more focused, effective and reliable and benchmarking is more fair if additional information is gathered to identify covariates and additional information to determine why the indicators change

In a study by de Olde et al. (2017), experts were asked to rank which criteria for indicator selection they considered most important for indicators aimed at measuring sustainable agriculture. The experts were from the New Zealand Sustainability Dashboard and Temperate Agriculture Research Network and were intended to represent researchers and consultants with expert knowledge on sustainability assessments of agricultural systems from many different regions. The results revealed a great lack of consensus on the criteria deemed most important. de Olde et al. (2017) explained some of the variation as a result of context, which is determined to be an important factor when choosing appropriate indicators.

C2. The relationship between data, indicators and indices

The 'information pyramid' is useful for understanding how concepts such as an index and indicators relate to each other (Fig. C1).

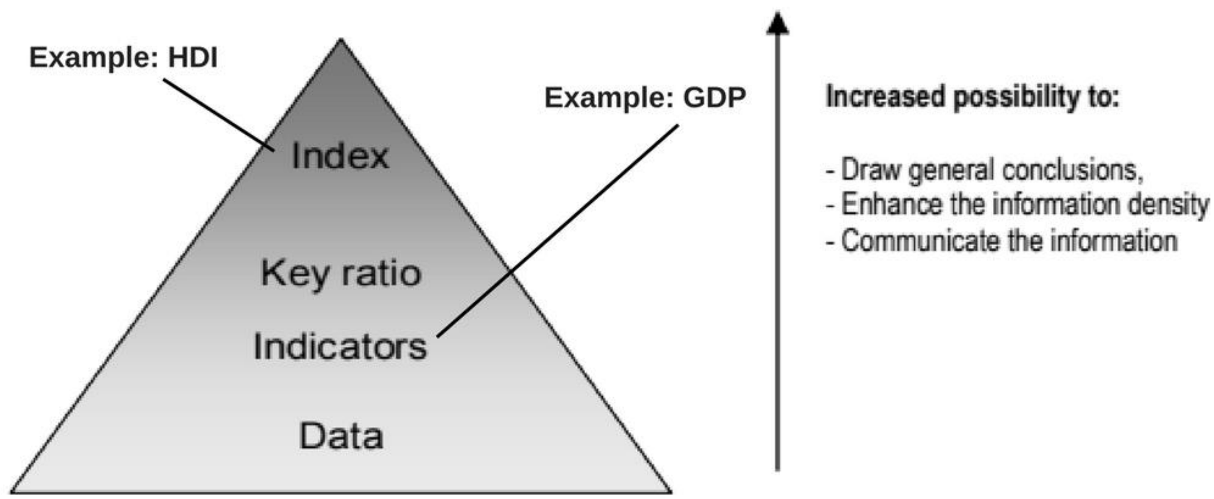

Fig. C2. The information pyramid. HDI: human development index, GDP: gross domestic product. From Mineur (2007) and examples added by the authors of the present report.

On moving up towards the top of the information pyramid, information becomes easier to communicate but at the same time it loses precision about the system it is trying to represent. The different categories in the pyramid can be defined as follows (Segnestam et al., 2002; Mineur, 2007):

- *Data* represent the most basic component of information and thus cannot be broken down to smaller or individual components. Data can be collected through measurements, surveys, observations, interviews or other relevant methods.
- *Indicators* are derived from data and represent or point to the state of a phenomenon. A commonly used indicator is gross domestic product (GDP).
- *Key ratio indicators* (also called headline indicators or core indicators) usually comprise well-selected indicators with high communicative value that indicate trends and prioritised areas. Unlike indicators, the key ratio indicators require an in-depth and holistic analysis of the system or society in order to act as the basis for policy decisions.
- *Index (or composite indicator)* is a set of aggregated or weighted indicators and is often used to compare or describe the state of systems. Indices are sometimes seen as more political tools for communication, rather than giving accurate information about the system in question. An example within the field of sustainable development is the Human Development Index (HDI), which is frequently used as a reference point of a nation's wellbeing. HDI is a composite measurement and comprises three dimensions: health and longevity, level of education and standard of living.

C3. Indicators and damage pathways

Indicators can measure different points in the causal chain of the damage pathway. To illustrate this for environmental issues, here we use the conceptual framework from life cycle impact assessment (LCIA). Along the impact pathway from resource use and emission of pollutants to final damage on ecosystems and human health, midpoint and endpoint indicators are defined which represent different types of impacts. The endpoint indicators try to capture what we ultimately want to protect, and commonly include: 1) damage to human health, 2) damage to ecosystems and 3) damage to resource availability, while the midpoint indicators describe intermediate steps in the cause-effect chain, e.g. human toxicity and global warming. The endpoint of human health is commonly measured as DALYs, as this is one of the most relevant endpoints for human health.

Appendix D. Review of sustainable diet indicators - an update of Jones et al.

Table D1 lists the exclusion criteria used by Jones et al. (2016). In order to encompass all relevant studies, Jones et al. (2016) applied a systematic search method covering 30 databases in the fields of nutrition, public health, agriculture, ecology, economics, social science, public policy and environmental and climate change. They also examined references of identified articles and prominent policy reports, previous literature reviews and archives of select indexed journals. The search was conducted with a uniform set of search terms with a priori exclusion criteria and no time period restrictions. Two reviewers then independently performed a first-stage screening of the title and abstract of English language peer-reviewed articles.

Table D1. Exclusion criterion used in Jones et al. (2016)

Exclusion criterion	**Description**
Non-peer-reviewed documents	Conference proceedings, non-peer-reviewed grey literature reports and/or discussion papers
Non-empirical study	Purely conceptual article with no empirical analytical component (i.e. no primary, secondary, or simulated data were analysed to examine specific, testable research questions); this included commentary, perspectives and review papers
Inapplicable use of “diet”	Use of “diet” was in reference to a weight loss plan
Inapplicable use of “sustainable”	Use of “sustainable” was in reference to the persistence of an intervention or programme, rather than the characterisation of diet or consumption patterns
No data on human diets	The article addressed animal diets or crop production only
Inapplicable to study objective	The study centred on the health of the intestinal mucosa (related to the term “econutrition”)
Focus on individual foods	The article examined environmental impacts of a single food or commodity, rather than overall dietary patterns or comparative food groups

In the updated search, the following papers were included:

Birney CI, Franklin KF, Davidson FT, Webber ME (2017) An assessment of individual foodprints attributed to diets and food waste in the United States. Environ Res Lett 1;12(10):105008.

Blas A, Garrido A, Willaarts B (2016) Evaluating the water footprint of the Mediterranean and American diets. Water. 2016 Oct 13;8(10):448.

Donati M, Menozzi D, Zighetti C, Rosi A, Zinetti A, Scazzina F (2016) Towards a sustainable diet combining economic, environmental and nutritional objectives. Appetite 106:48–57.

Donini LM, Dernini S, Lairon D, Serra-Majem L, Amiot M-J, del Balzo V, et al. (2016) A consensus proposal for nutritional indicators to assess the sustainability of a healthy diet: The Mediterranean diet as a case study. Frontiers in Nutrition 3:37.

van Dooren C, Aiking H (2016) Defining a nutritionally healthy, environmentally friendly, and culturally acceptable Low Lands Diet. Int J Life Cycle Assess 21(5):688–700.

van Dooren C, Douma A, Aiking H, Vellinga P (2017) Proposing a novel index reflecting both climate impact and nutritional impact of food products. Ecol Econ 131:389–98.

Gustafson D, Gutman A, Leet W, Drewnowski A, Fanzo J, Ingram J (2016) Seven food system metrics of sustainable nutrition security. Sustainability 23;8(3):196.

Hadjikakou M (2017) Trimming the excess: environmental impacts of discretionary food consumption in Australia. Ecol Econ 131:119–28.

Harris F, Green RF, Joy EJM, Kayatz B, Haines A, Dangour AD (2017) The water use of Indian diets and socio-demographic factors related to dietary blue water footprint. Sci Total Environ 587–588:128–36.

He X, Qiao Y, Liu Y, Dendler L, Yin C, Martin F (2016) Environmental impact assessment of organic and conventional tomato production in urban greenhouses of Beijing city, China. J Clean Prod 134:251–8.

Hendrie G, Baird D, Ridoutt B, Hadjikakou M, Noakes M (2016) Overconsumption of energy and excessive discretionary food intake inflates dietary greenhouse gas emissions in Australia. Nutrients 31;8(12):690.

Horgan GW, Perrin A, Whybrow S, Macdiarmid JI (2016) Achieving dietary recommendations and reducing greenhouse gas emissions: modelling diets to minimise the change from current intakes. Int J Behav Nutr Phys Act 13(1)

Hyland JJ, Henchion M, McCarthy M, McCarthy SN (2017) The climatic impact of food consumption in a representative sample of Irish adults and implications for food and nutrition policy. Public Health Nutr 20(04):726–38.

Lukas M, Rohn H, Lettenmeier M, Liedtke C, Wiesen K (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. J Clean Prod 132:161–70.

Ribal J, Fenollosa ML, García-Segovia P, Clemente G, Escobar N, Sanjuán N (2016) Designing healthy, climate friendly and affordable school lunches. Int J Life Cycle Assess 21(5):631–45.

Rosi A, Mena P, Pellegrini N, Turroni S, Neviani E, Ferrocino I, et al. (2017) Environmental impact of omnivorous, ovo-lacto-vegetarian, and vegan diet. Sci Rep 7(1).

Röös E, Patel M, Spångberg J, Carlsson G, Rydhmer L (2016) Limiting livestock production to pasture and by-products in a search for sustainable diets. Food Policy 58:1–13.

Serafini M, Toti E (2016) Unsustainability of obesity: Metabolic food waste. Front Nutr 3(40).

Sjörs C, Raposo SE, Sjölander A, Bälter O, Hedenus F, Bälter K (2016) Diet-related greenhouse gas emissions assessed by a food frequency questionnaire and validated using 7-day weighed food records. Environ Health 15(1).

Springmann M, Godfray HCJ, Rayner M, Scarborough P (2016) Analysis and valuation of the health and climate change cobenefits of dietary change. Proc Natl Acad Sci 113(15):4146–4151.

Tessari P, Lante A, Mosca G (2016) Essential amino acids: master regulators of nutrition and environmental footprint? Sci Rep 6(1).

Tyszler M, Kramer G, Blonk H (2016) Just eating healthier is not enough: studying the environmental impact of different diet scenarios for Dutch women (31–50 years old) by linear programming. Int J Life Cycle Assess 21(5):701–9.

Ulaszewska MM, Luzzani G, Pignatelli S, Capri E (2017) Assessment of diet-related GHG emissions using the environmental hourglass approach for the Mediterranean and new Nordic diets. Sci Total Environ 574:829–36.

Yue Q, Xu X, Hillier J, Cheng K, Pan G (2017) Mitigating greenhouse gas emissions in agriculture: From farm production to food consumption. J Clean Prod 149:1011–9.

Appendix E. Examples of currently used indicators for sustainable diets

In this section, we describe in more detail some of the indicators used in different studies (taken from Jones et al. (2016) and identified in our complementary search) to assess the sustainability of diets.

E1. Climate change

The most common way to assess the climate impact of a diet is to quantify the total amount of emissions of GHG (including carbon dioxide, nitrous oxide and methane) associated with production of the foods in the diet. This is also called the carbon footprint of the diet. Data on the climate impacts of individual foods are commonly collected from LCA studies and multiplied by the amount of a specific food in the diet to calculate the total climate impact from the diet.

There are several different types of LCA studies used to calculate the climate impact of different foods:

- **Process-based LCA**
  This is the most common type of LCA and studies the emissions and resource use from a bottom-up perspective considering the processes involved in the production of a product.
- **Consequential LCA**
  Consequential LCA (as opposed to attributional LCA) aims at evaluating the consequences of a change in demand for a product. Consequential LCA can therefore be more useful in a decision-making process, as it analyses the consequences of certain activities.
- **Input-output model LCA**
  Input-output model LCA uses monetary transactions to determine the environmental impact of goods and services and how they relate to other industries.
- **Hybrid LCA**
  Hybrid LCA combines economic input-output models with process-based LCA.

Instead of using the LCA approach of multiplying the amount of food in the diet by its respective carbon footprint, emissions of GHG from different diets can also be modelled using biophysical or economic models that include emissions of different pollutants. This approach was applied by Westhoek et al. (2014) to model the effect on health and environment of reducing meat and dairy intake in Europe by 50%. Modelling approaches based on biophysical or economic models are more complex and less transparent than the LCA approach, but are better able to account for dependencies in production systems and biophysical and economic limits in production. For example, when using the LCA approach to calculate the GHG emissions from e.g. a lacto-vegetarian diet, this would not account for the emissions allocated to the beef meat that is inevitably produced in the dairy system.

E2. Land use

The most common method for determining the requirement for land of a specific food item is as follows: 1) the agricultural product that forms the basis of a food product is determined (for pasta this would be wheat), 2) the amount of agricultural product needed for 1 kg of food product (pasta) is then determined (in the case of pasta, it takes approximately 1.4 kg of wheat to produce 1 kg of pasta). This value is divided by the yield of the crop (kg/ha), giving the area needed to produce 1 kg of the given food product (Temme et al., 2013). Similarly, for animal products, the type and amount of feed are used to calculate the land requirement.

Land use is commonly divided into different land types, although some studies show results of land use on an aggregated level only. The importance of differentiating between different types of land is important, as described by Hallström et al. (2014):

"When discussing availability of agricultural land it is necessary to distinguish between different types of land [...] However, only some 30% of agricultural land available consists of cropland. Meadows and pastures, which represent the remaining agricultural area, are only to a limited extent suitable for cultivation. As the majority of current global food supply is dependent on cultivated land pressure on agricultural land is especially intense on cropland."

Peters et al. (2007) calculated annual per capita land requirement based on dietary intake, crop yield and livestock feed requirements. Three types of land use were accounted for: cropland usable for all crops, cropland limited to perennial crops and pasture, and land limited to pasture. To account for annual variation in yields, land requirement was calculated using five years of crop data. In an paper by Meier et al. (2014), land use for German consumption patterns was analysed using seven land types in total: arable land (domestic or abroad), pastures (domestic or abroad), permanent culture (domestic or abroad) and forest (wood production for pallets, paper production for packaging material). Eshel et al. (2014) analysed the environmental impact of the US diet and for dairy and beef production included three different land types: pastureland, cropland and processed roughage land. Those authors discuss the important distinction that these livestock systems use pastureland and not cropland, as these pasture lands, at least in the western US, are unfit for crop production.

Stehfest et al. (2009) used IMAGE (Integrated Model to Assess the Global Environment), which includes cropland and grassland as the main land types. For livestock systems, two variants are included: pastoral and mixed/landless systems. Pastoral systems cover about two-thirds of the global area of permanent pasture and are dominated by ruminant grazing. Landless ruminant production systems are included in mixed/landless systems, since they have the same interrelationships with crop and grass production systems (feed crops, fodder, manure, etc.) as livestock production in mixed systems.

Arnoult et al. (2010) used a Land Use Allocation Model (LUAM) to analyse the landscape effects in the UK of a dietary change to a healthy recommended diet according to the UK Department of Health. Three main land types were identified: arable/grass ley, permanent pasture and rough pasture.

Some studies have used the 'ecological footprint' (EF) methodology to describe land use, e.g. Fairchild and Collins (2011) and Downs and Fanzo (2015). The EF measures how much biologically productive land and sea is needed to support the consumption by an individual or region. Biologically productive land and sea include cropland, forest and fishing grounds and space for infrastructure and the land needed to absorb waste products generated by human activities. The unit of EF is 'global hectares' (gha) and is usually expressed on a yearly basis for a given population.

E3. Water use

The papers included in the review by Jones et al. (2016) often refer to the definition of a water footprint (WF) as set out by the Water Footprint Network (Hoekstra et al., 2011). The WF is the demand for freshwater resources required in all life cycle steps to produce goods and services. It represents a measure of human appropriation of freshwater, which is measured as volume of water used. Water use can be direct or indirect, where direct use is the individual's direct consumption of water, such as water for cooking, whereas indirect use, sometimes called 'virtual water', is the water needed for all goods and services earlier in the supply chain. In addition, water is divided into green, blue and grey water. Blue water is surface or groundwater, green water is rain water or moisture stored in the topsoil layer and grey water is the volume of freshwater needed to 'assimilate a load of pollutants' caused by the activity in question. The grey water volume is affected by the natural background concentration of pollutions and existing water quality standards. As blue water in some respect represents water as a finite resource, it is common to let blue water represent the overall WF (Eshel et al., 2014).

Methodologies to account for differences in the actual impact of water use given regional differences in water scarcity have also been developed (Ridoutt and Pfister, 2010). Hess et al. (2015) suggests an indicator called Water Stress Index (WSI) which reflects blue water availability. The WSI is expressed as a number between 0.01 and 1, where a value <0.01 indicates no water stress, values between 0.1 and <0.2 indicate low water stress, values between 0.2 and <0.4 indicate moderate water stress, values between 0.4 and <0.8 indicate high water stress and values >0.8 indicate very high water stress. Hess et al. (2015) used the WSI to calculate a blue water scarcity footprint (WSF) (m^3 H_2O equivalents) which reflects the equivalent amount of water withdrawn from a water body at the global average level of water stress.

There is some controversy as to whether water use quantification or including water stress is most appropriate. Hoekstra (2016) lists the potential pitfalls and dangers of weighting the water footprint with water stress or scarcity and argues that the WSI obscures the debate of water resources, neglects the importance of green water scarcity, is inconsistent with how other environmental footprints are designed and lacks 'meaningful physical interpretation'. A recent consensus building process within the UNEP-SETAC Life Cycle Initiative recommends the use of the AWARE method which is based on *"the quantification of the relative available water remaining per area once the demand of humans and aquatic ecosystems has been met"* (Boulay et al., 2018).

E4. Energy use

One common method for evaluating energy use in relation to diets or food items is the Cumulative Energy Demand, which corresponds to the primary energy use, i.e. the amount of energy as it is found in nature before any human-engineered conversion or transformation has been applied. Davis and Sonesson (2008) analysed different meals using several environmental impact categories and report results for both primary energy and secondary energy use, where the latter is energy that has been converted to more 'convenient forms of energy' (sic) such as electricity.

Some studies make a distinction between renewable and non-renewable energy. For example, He et al. (2016) evaluated energy use of two different agricultural systems using the demand for non-renewable energy resources. This assessment included energy used to produce fertilisers and pesticides and the amount of diesel used on farms (evaluated through interviews with farmers). Energy use was then aggregated into an impact category called 'Energy depletion', which measured energy use (MJ) per tonne of produce.

Several studies have energy use incorporated into aggregate methods, such as the Ecoindicator95+ or ReCiPe life cycle impact assessment methods, where energy use is combined with other impact categories to yield an overall environmental score (e.g. Baroni et al., 2007, 2014; Tyszler et al., 2016).

Coley et al. (2009) conducted analyses on different models for consumer shopping habits, where the distance travelled by car assigned for shopping was compared with a centralised system where food was instead transported to a semi-local hub of the retailer. Different types of fuel and energy use were calculated, but were not related to food production specifically, but rather to consumer activities 'around' food.

E5. Biogeochemical flows

One of the most commonly used metrics to assess the impact of foods, meals and diets on biogeochemical flows is Eutrophication Potential (EP) (Guinée et al., 2002). The EP accounts for different types of nutrient pollution (including nitrate leaching from fields, emissions of ammonia from manure management, phosphate runoff from fields etc.) by aggregating their impact based on how much each substance contributes (in terms of mass) to forming a typical aquatic organism, commonly an alga. In its simplest form, the EP do not consider any site-specific issues, e.g. the nutrient that is limiting in a certain waterway or how much of a certain substance actually reaches the waterway (fate). Such a simple EP method was used by e.g. Muñoz et al. (2010), while Saarinen et al. (2012) used site-specific factors for Finland. Since the actual negative impact from the release of nutrients into the environment is highly site-specific, regional factors that include more relevant factors along the damage pathway are preferable. However, when looking at diets including many food categories, it is not always possible to trace products back to the actual sites where production takes place and, even if it is, regional factors might not be available.

Other indicators in this area include 'added nitrogen' (Eshel et al., 2014; Gill et al., 2015) and 'phosphorus use' (Meier and Christen, 2013; Gill et al., 2015), hence using the amount of 'new nutrients' added into the agricultural system as a proxy for the imbalances caused by agriculture in terms of biogeochemical flows. The nitrogen footprint is another indicator, defined as *"the total direct N-losses to the environment that occur for the production of one unit of (food) product, measured in g N/kg food product"* (Leip et al., 2014). Leip et al. (2014) also introduce the 'nitrogen investment factor', defined as the external N required to produce one unit of product in terms of N contained.

Westhoek et al. (2014) modelled decreased consumption of meat and dairy in Europe using several indicators, including added nitrogen, emissions of nitrate to groundwater and surface water, emissions of ammonia to air and nitrogen use efficiency.

Similarly to the EP, there is also a method for quantifying the Acidification Potential (AP) that some studies have used. As the AP from agriculture is dominated by emissions of ammonia, using 'ammonia emissions' as an indicator, as done e.g. by Meier and Christen (2013) and Westhoek et al. (2014), is a good proxy for the acidification for foods and diets if post-farm stages do not add considerable amounts of acidifying substances from energy use.

E6. Biodiversity

The review by Jones et al. (2016) included only one paper assessing the impacts of different diets on biodiversity (Röös et al., 2015a) and our complementary search identified another two articles (Röös et al., 2016a; Gustafson et al., 2016).

Röös et al. (2015a) investigated biodiversity damage potential (BDP) from land use with a method developed by de Baan et al. (2012). The method assesses the impact on biodiversity on a global scale and is based on differences in species richness between land use types. The data inputs are: hectares of land occupied, classified by land type (annual crops, permanent crops, pastures and meadows) and biome (natural vegetation type, e.g. temperate broadleaf forest or tropical savannah). The resulting BDP is based on differences in species richness between agricultural and natural land use of the biome. One limitation with this method is that the positive biodiversity effects of semi-natural pasture in Sweden and around Europe are not included in BDP, nor are potential benefits from organic production. Another limitation is that positive biodiversity effects by preservation of agricultural land in forest-dominated regions, for example in Sweden, are not included in the method.

A later paper by Röös et al. (2016a) created three scenarios based on the concept of 'livestock on leftovers' for livestock production (see section 4.7). Biodiversity impacts were not quantitatively assessed, but the preservation of current semi-natural grassland and arable land in Sweden was set as a boundary condition.

Gustafson et al. (2016) defined seven metrics (each based on a combination of multiple indicators) for use in characterising sustainable nutrition outcomes of food systems (section 4.3) and used the indicator 'Ecosystem Status', one of five indicators of the metric 'Ecosystem Stability'. The data used for the indicator Ecosystem Status are underlying national data for Environmental Performance Index (EPI)[38]. The EPI is used to rank countries using 24 performance indicators for environmental health (household solid fuels, PM2.5 exposure and exceedance, drinking water, sanitation, lead exposure, air and water quality and heavy metals) and ecosystem vitality (indicators related to biodiversity and habitat, forests, fisheries, climate and energy, air pollution, water resources and agriculture). Although many of these are related to food production, many are not directly so, which makes this index a blunt instrument for describing food system biodiversity impacts. Gustafson et al. (2016) point out that it would be desirable to include additional measures of ecosystem status, such as desertification, salinisation and soil degradation, in this indicator. Chaudhary et al. (2018), who applied the SNS framework, therefore added the indicator Biodiversity Footprint (Chaudhary and Kastner, 2016) to the Ecosystem Stability metric, which enabled the land use biodiversity impacts associated with internationally traded foods to be accounted for. Chaudhary and Kastner (2016) quantified biodiversity impacts from habitat loss/degradation due to land use for cropping by assessing the species loss by a specific land use compared with the original natural habitat. However, crop production also leads to negative impacts on biodiversity, from e.g. nutrient leaching from fields causing eutrophication of waterways and other damage pathways that this method does not capture. Hence, biodiversity impacts are probably underestimated. Quantifying impacts on biodiversity from all such pathways is highly challenging.

In the general LCA literature, several methods for capturing the biodiversity impacts from land use have been suggested (Curran et al. (2016) provide an overview and Chaplin-Kramer et al. (2017) provide some further interesting advances). However, the review by Jones et al. (2016) and our follow-up search showed that these have not yet been used extensively in assessing the sustainability of diets, probably due to lack of data.

E7. Social equity

It is difficult to find an indicator that measures social equity in relation to food and diets in a straightforward manner. None of the studies investigated explicitly measured social equity. However, some other concepts might be useful to capture social equity in relation to food, for example, the distribution of food. Since the FAO has data on the calorie consumption of different regions, as well as divided between calories from plant and animal products, we can easily handle calories (and their origin) in the same manner as sociologists and economists would handle income. Through indicators such as the Gini coefficient and Hoover concentration index, we can determine the distribution of calories between countries and regions and easily measure when equity is falling or rising in the world (White, 2000). By relating calorie consumption to environmental impact of a region's food consumption, we can also measure whether all countries or regions 'contribute' to environmental issues equally. White (2000) also relates food consumption of a region or a country to its food production, i.e. how much global land is taken to uphold a country's consumption level. This also relates to the production

[38] https://epi.envirocenter.yale.edu/

capacity of a country, where countries or regions that produce less than they consume would contribute to injustice in the distribution and consumption of food. White (2000) also discusses different indicators for evaluating the diversity of food items in a particular food system, where large differences in food system diversity could be a relevant indicator of injustice in the availability of food.

Gustafson et al. (2016) provide metrics for 'sustainable nutrition security', where several indicators might be useful. The dimensions 'food nutrient adequacy', 'food affordability and availability' and 'sociocultural wellbeing' all have some indicators that try to evaluate certain aspects of social and nutritional equity in a country or a region. Furthermore, Gustafson et al. (2016) use indices for child labour, gender equity and respect for community rights to evaluate sociocultural wellbeing.

There are several labelling schemes to enable consumers to purchase foods that have been produced with social aspects accounted for, Fairtrade being one of the best known. The studies included in the review by Jones et al. (2016) only analysed consumer perception in relation to Fairtrade products, and not the impact of diets containing Fairtrade products on social equity.

E8. Animal welfare

As with the topic of social equity, the few studies that mention animal welfare do this in relation to consumer behaviour and determinants of food purchases. Gustafson et al. (2016) include the indicator 'Animal Protection Index', which ranks countries from a high 'A' to a low 'G'. However, as with social equity, this is on a country rather than on a diet basis. Scherer et al. (2017) present a framework for including animal welfare in LCA and exemplify this for eight products; beef, pork, poultry, milk, eggs, salmon, shrimps and insects, which could enable inclusion of this aspect in assessments on dietary level.

E9. Cultural appropriateness

Few studies to date have considered the cultural appropriateness of diets. One rare example is the study by Wilson et al. (2013), in which the authors constructed 'familiar' meals with constraints regarding cost and GHG emissions. Some studies that have optimised diets for nutrient adequacy and low environmental impacts have included the constraint that the diets should resemble current eating patterns in term of amounts of different food types in the diet (Kramer et al., 2017; Vieux et al., 2018). Capturing the cultural appropriateness of diets is highly challenging, as diets are constantly changing and highly variable among population groups (Röös et al., 2016a).

Appendix F. Sustainable dietary recommendations

Table F1. Official dietary guidelines that include sustainability

Country, link to more information	**Summary of advice on:** ● **Sustainability (first bullet)** ● **Dairy and plant-based dairy alternatives (second bullet)**
Germany (2013). http://www.fao.org/3/a-i5640e.pdf page 18-20	● The actual text only provides some mention of environmental issues. Each guideline is followed by a brief paragraph expanding on the particular issue. While there is no mention of sustainability in the top level messaging, some of the explanatory paragraphs do contain sentences that refer to sustainability or the environment. ● Consume milk and dairy products daily. Choose low fat. No advice on plant based alternatives.
Brazil (2014). http://www.fao.org/3/a-i5640e.pdf page 23-28	● Sustainability is a cross-cutting theme in the guidelines, if not always explicitly articulated. The third principle of the guidelines is: “healthy diets derive from socially and environmentally sustainable food systems”. Each recommendation in the ‘Choosing foods’ chapter is followed by the rationale behind the recommendations, including health, environmental and social implications. However, the summary of main recommendations only briefly mentions environmental sustainability. ● Milk drinks and yogurts that have been sweetened, coloured and flavoured are ultra-processed foods, and as such should be avoided. No advice on plant-based alternatives.
Sweden (2015). http://www.fao.org/3/a-i5640e.pdf page 28-32	● Sustainability is embedded throughout the guidelines – the document actually begins with a prologue entitled “Sustainable big picture”. On entering the main website of the NFA, the first, highly visible, subheading on the site is “Food habits, health and environment”. The document highlights a broad range of environmental concerns, from climate change to pesticide use and the eutrophication of water bodies. It touches too on broader sustainability issues, such as animal welfare and antibiotic use in farm animals. Unlike most of the other guidelines reviewed, it also considers some of the complexities inherent in defining sustainability. ● Choose low-fat, unsweetened products enriched with vitamin D. No advice on plant-based alternatives.
Nordic countries: Nordic Nutrition Recommendations (NNR) (2012): http://norden.org/en/theme/former-themes/themes-2016/nordic-nutrition-recommendation/nordic-nutrition-recommendations-2012 page 137-154	● The Swedish dietary guidelines are based on the Nordic Nutrition Recommendations (NNR) and the Swedish national dietary survey, which takes into account the specific dietary pattern of the Swedish population. NNR are released every eight years and aim to create recommendations on micro- and macronutrients for the population in the Nordic countries. A chapter on “sustainable food consumption - environmental issues” was included for the first time in the latest edition of NNR, released in 2012. The chapter also included a presentation of possible dietary changes from current consumption patterns to reach a sustainable diet. The Swedish National Food Agency is the first, and as of today the only, Nordic stakeholder to translate the sustainable food recommendations into national dietary guidelines. ● See section 5.2.3
Qatar (2014). http://www.fao.org/3/a-i5640e.pdf page 33-35	● The Qatar guidelines include “eat healthy while protecting the environment” as one of the eight guidelines. The section of the document dedicated to this guideline starts by justifying the inclusion of sustainability in the recommendations, describing some of the ways food is linked to the environment. That section offers advice on how to eat sustainably. Almost all references to sustainability are limited to this section. The only exception is in the section about fish, where the guidelines recommend looking in “online seafood guides” for information about the “healthiest and most environmentally friendly” products. Most notably, the section on meat and meat alternatives does not discuss the environmental impact of those products – although it does

	recommend eating at least one meatless meal per week, limiting red meat consumption to 500g per week and avoiding processed meats. • Consume milk and dairy products daily. Choose low fat. If you do not drink milk or eat dairy products, choose other calcium- and vitamin D-rich foods (e.g. fortified soy drinks, almonds, chickpeas)

Table F2. Quasi-official guidelines.

Country/guide, link to more information	Summary of advice on sustainability
Germany. The Sustainable Shopping Basket (2013). http://www.fao.org/3/a-i5640e.pdf page 21 https://friendsoftheearth.uk/sites/default/files/downloads/Sustainable_diets_January_2016_final.pdf page 25	The German government has supported the development of guidelines to inform purchasing decisions: The Sustainable Shopping Basket. The recommendations for reducing meat consumption (to between 300 and 600 g per week) and to consume 5 servings of fruit and vegetables every day are based on the German dietary guidelines.
Germany. AID-Food Pyramid. http://www.fao.org/3/a-i5640e.pdf page 22	The German Agency for Consumer Information (AID) information service has developed its own pyramid, based on the German dietary guidelines, but presents simplified food groups. The AID website has a section on advice on nutrition and climate protection.
The Netherlands (2011). Guidelines for a healthy diet: the ecological perspective. http://www.fao.org/3/a-i5640e.pdf page 38-41	Environmental analysis of the 2006 Dutch guidelines for a healthy diet
The Netherlands (2015). Dutch Dietary Guidelines, 2015 Summary ("The guidelines in brief"): https://www.gezondheidsraad.nl/sites/default/files/guidelines_in_brief_201524edutch_dietary_guidelines_2015_0.pdf Complete publication: https://www.gezondheidsraad.nl/sites/default/files/201524edutch_dietary_guidelines_2015.pdf page 78	The Health Council of the Netherlands published new Dutch dietary guidelines in 2015. The guidelines focus on health. The summary of Dutch dietary guidelines does not mention any other sustainability consideration except health. The complete publication also focuses on health, but sustainability considerations are mentioned in half a page of text about ecological aspects. The Committee has concluded that: "as well as having health benefits, following a number of the recommendations would lead to dietary patterns with ecological benefits... Generally speaking, a diet that includes less food from animals and more plant-based food has a lower ecological burden than a conventional Dutch diet. From that perspective, it is advisable to moderate high dairy product consumption as well".
Estonia http://www.fao.org/3/a-i5640e.pdf page 46	The dietary guidelines (2006) do not mention sustainability. However, the website that hosts the guidelines presents an updated version of the principles upon which a healthy diet is based, with the inclusion of the following principle: "Eat in an environmentally conscious way (this includes: 1) plant based, 2) biologically diverse and species rich, 3) local, seasonal and traditional, and 4) produced sustainably".
United Kingdom (2007) http://www.fao.org/3/a-i5640e.pdf page 47-51 and "The principles of healthy and sustainable eating patterns. Follow-on work to the Green Food Project, focusing on sustainable consumption" by Tara Garnett and Maureen Strong (2014). These authors also co-chaired the working groups for this report.	The dietary guidelines (2007) do not mention sustainability. However, the UK government enabled a multi-stakeholder process, which led to eight "Principles of healthy and sustainable eating patterns". Each principle is communicated by a short headline message, followed by a brief explanation of the message and the rationale behind it, relevant qualifiers and caveats to the advice provided and a list of the literature sources to support of each recommendation. Note that the principles are not owned or endorsed as such by Government.

United Kingdom (2016) The Eatwell Guide has replaced the Eatwell Plate and continues to define the government's advice on a healthy balanced diet. https://www.gov.uk/government/publications/the-eatwell-guide and https://www.carbontrust.com/resources/reports/advice/sustainable-diets/	The dietary guidelines (2016) have the headline "Use the Eatwell Guide to help you get a balance of healthier and more sustainable food". The names of the food group segments have been updated to place emphasis on certain food products within a food group that can be considered more environmentally sustainable. For example, the pink segment is named "Beans, pulses, fish, eggs, meat and other proteins' to highlight the contribution non-meat sources make to protein intake. Sustainability issues are also discussed when it comes to seafood. According to the Carbon Trust analysis, the Eatwell Guide shows an appreciably lower environmental impact than the current UK diet. We note that parallel improvements in production efficiency and waste reduction will help too. A number of differences contribute to the reduction, such as increasing potatoes, fish, wholemeal & white bread, vegetables and fruit whilst reducing amounts of dairy, meat, rice, pasta, pizza and sweet foods.
France (2002) http://www.fao.org/3/a-i5640e.pdf page 51	The dietary guidelines (2002) do not mention sustainability. However, the French Agency for the Environment and Energy has produced a set of recommendations aimed at individuals and "eco-citizens" to promote sustainable shopping habits. A section of their website called "Mes Achats" (My purchases) provides three main messages: to promote seasonal products, to 'adopt diets that combine health, environment and fun' (i.e. replace a meat dish with one based on grains or legumes once a week), 'buy products with environmental labels', and limit food waste.
Sweden, Eat S.M.A.R.T. http://www.wageningenacademic.com/doi/abs/10.3920/978-90-8686-187-3_15	The 'Eat S.M.A.R.T.' concept was first released in Sweden in 2001 by Stockholm County Council and the latest update was in 2008. The concept is still used in different contexts in Sweden, for example in the Swedish city of Malmö. (Information in Swedish: http://folkhalsoguiden.se/amnesomraden/mat/informationsmaterial/smart/)
Healthy and sustainable eating with the Flemish Food Triangle. The Food Triangle is based on an extensive literature review and consultation with experts. The result is a realistic and sustainable model that fits perfectly with Flemish eating culture. Link:https://www.gezondleven.be/files/voeding/Healthy-Living-2017-Food-Triangle.pdf	1. Eat proportionally more foods that are derived from plants than foods that are derived from animals. 2. Avoid ultraprocessed foods as much as possible 3. Don't waste food. Moderate your consumption

Table F3. Non-official sustainable dietary guidelines

Organisation, link to more information	**Summary of advice on sustainability**
WWF UK: LiveWell (2011) http://www.fao.org/3/a-i5640e.pdf page 52-53 http://assets.wwf.org.uk/downloads/livewell_report_jan11.pdf WWF Europe: LiveWell for LIFE http://livewellforlife.eu/knowledge-centre	Project initiated by WWF UK, where researchers developed diets that conformed to the government's dietary guidelines and also achieved reductions in absolute food-related greenhouse gas emissions. The project and its approach were subsequently extended to Sweden, France and Spain under the name Livewell for LIFE. Although it has no official status, LiveWell has been instrumental in introducing sustainable diets onto the European political agenda. Based on the experiences gained, WWF now promotes the "6 Livewell Principles".
WWF UK: Eating for 2 degrees – new and updated Livewell Plates (2017) https://www.wwf.org.uk/eatingfor2degrees	New Livewell report which looks at what we need to eat between now and 2030 to meet our Paris Agreement commitments. Besides carbon reduction targets, the report includes further environmental criteria – particularly water use and land footprint. The report also includes Livewell Plates for adolescents, the elderly and vegans for the first time.
Barilla Center for Food and Nutrition (BCFN): Barilla double pyramid (version 6th: 2015) http://www.fao.org/3/a-i5640e.pdf page 53-54	The model presents two pyramids. The first is the familiar food pyramid – in this case, based on the principles of the Mediterranean diet. The second is inverted and reclassifies foods according to their environmental impact, with the most damaging foods placed at the top.
Food Climate Research Network (FCRN) - Changing what we eat - http://www.fao.org/3/a-i5640e.pdf page 55 http://www.fao.org/3/a-i5640e.pdf Box 1 on page 1 "Characteristics of low environmental impact diets consistent with good health".	Report based on discussions arising from a workshop in April 2014, organised by the FCRN, funded and hosted by the Wellcome Trust with additional support from the UK" s multi-agency Global Food Security programme. The aim of the workshop was to bring together academic researchers spanning diverse disciplines, as well as stakeholders from business & civil society, to consider the state of thinking on sustainable healthy eating and food systems and begin scoping a research agenda on how our eating practices might be shifted in healthier and more sustainable directions. The report includes a list of the 10 general principles of sustainable healthy diets. The list was previously published in https://fcrn.org.uk/sites/default/files/fcrn_wellcome_gfs_changing_consumption_report_final.pdf Box 1 on page 8: "Characteristics of healthier and less GHG- and land-intensive eating patterns".

The only quasi-official guidelines that mention dairy and plant-based dairy alternatives are the UK Green Food Project, which states: "*Include milk and dairy products in your diet or seek out plant based alternatives, including those that are fortified with additional vitamins and minerals.*" Among the non-official guidelines, it can be noted that the Barilla pyramids have cheese towards the top, while milk and yogurt are in the middle of the pyramid. The FCRN's *Changing What We Eat* report say that dairy products or alternatives, i.e. fortified milk substitutes and other foods rich in calcium and micronutrients, should be eaten in moderation.

Appendix G. Fortification

Calcium

In a systematic review by Rafferty et al. (2007), the question of bioavailability of calcium supplements and fortification was assessed. The authors concluded that calcium uptake depends on several factors, such as associated salt, size of calcium load, vitamin D status and the associated matrix, i.e. calcium suspended in food or liquid. For calcium suspended in a matrix (as is the case for plant-based dairy alternatives), the absolute absorption fraction varied between 24 and 40 %. In relation to cow's milk, calcium uptake varied between 81.7 and 111.4 %.

The most common calcium fortificants for soy milk on the American market are calcium carbonate (CC) and tricalcium phosphate (TCP) (Zhao et al., 2005). According to Heaney et al. (2000), TCP in soy milk has 25% lower uptake than calcium from cow's milk. This was confirmed by Zhao et al. (2005), who found that CC in soy milk had the same fractional absorption as that in cow's milk (both ~21%), whereas TCP in soy milk had lower fractional absorption (~18%). Zhao et al. (2005) concluded that higher absolute fortification with TCP in soy milk can compensate for the slightly lower fractional absorption, thus making it a viable fortification agent.

Vitamin D

Vitamin D is formed from cholesterol in humans when sunlight hits the skin, thus making intake of vitamin D redundant in theory. In practice, however, vitamin D deficiency is very common in some populations, especially in the northern hemisphere where the body's ability to form vitamin D is inhibited during the winter season (Melina et al., 2016). Dietary intake of vitamin D is therefore recommended. Vitamin D is present in two different forms, D_2 (ergocalciferol) and D_3 (cholecalciferol).

While D_2 is exclusively derived from plants, D_3 can be derived from both plants and animals (although the majority of supplements and food fortification agents use D_3 derived from animals). In a systematic review and meta-analysis, Tripkovic et al. (2012) investigated the effect of D_3 and D_2 on raising serum levels of vitamin D for bolus doses (large doses given infrequently) and for all protocols combined, Vitamin D_3 was found to be more efficacious than D_2 in raising plasma levels of vitamin D. However, when daily supplementation (25-100 µg per day) was analysed separately, there was no difference in efficacy between the two forms of vitamin D. However, the recommended daily intake of vitamin D is defined by most nutrition authorities to be between 7.5 µg and 15 µg, significantly lower than was investigated in any of the trials in the systematic review. In a recent trial with the same lead author, Tripovic et al. (2017) investigated whether smaller daily doses of 15 µg of vitamin D_2 versus D_3 as a food fortificant differed in their effect in raising serum levels of vitamin D. Both forms of vitamin D managed to satisfactorily raise the serum level of vitamin D, but vitamin D_3 was twice as efficacious as D_2 in raising serum levels (by 74-75%, compared with 33-34% for vitamin D_2. In conclusion, even if vitamin D_2 is satisfactory in raising serum levels of vitamin D, a higher fortification level might be warranted in order to achieve the same magnitude of effect as with vitamin D_3.

Iodine
Since dairy products are a source of iodine and plant-based dairy are not, how the individual's iodine status is affected by iodine fortification is a relevant question. The literature on iodine fortification in liquids is scarce, but iodine fortification in general is a more established topic. Organic iodine biofortification is subject to cooking losses under some circumstances (Cerretani et al., 2014), although not in the majority of the cases, and the stability of iodised salt in the form of potassium iodate seems to be stable up to 350 degrees Celsius (Bhatnagar et al., 1997). A commercial fruit drink (NutriStar™) fortified with several vitamins and minerals (iodine included) showed excellent bioavailability of all nutrients included (Mehansho et al., 2003).

Riboflavin
Riboflavin plays a small but important part in human energy metabolism. Deficiency leads to inflammation of the mouth cavity and possibly birth defects if it occurs during pregnancy. Riboflavin is slightly sensitive to light and humidity, but otherwise considered a stable micronutrient (Gadient, 1986). Absorption of free riboflavin is estimated to be 50-60% in doses from 2 to 25 mg (NNR, 2014).

Vitamin B12
Vitamin B12 is a vitamin that is exclusively found in animal-derived foods, such as dairy, meat and eggs. Inactive analogues may be found in certain plant foods, such as algae. Since these analogues only block the receptor for the uptake of B12, these types of food should not be taken simultaneously with B12-rich foods (NNR, 2014). In the early stages, B12 deficiency typically leads to anaemia and later to nerve cell damage. The most common form of B12 in food supplements and fortified foods is cyanocobalamin. The different forms of B12 are estimated to have approximately the same bioavailability (Adam et al., 1971). Vitamin B12 is slightly sensitive to temperature, oxygen and humidity, but otherwise considered stable (Gadient, 1986).

Environmental impacts from fortification agents
Data on the environmental impact of fortification agents are scarce. In a Master's project at Lund University, the environmental impact of fortification agents for oat drink was estimated and found to be relatively small compared with the impact of the rest of the production (Jarlbo, 2016). More research is needed in this area in order to quantify the magnitude of the environmental impact from fortification. A relevant contribution to this discussion is that fortification of dairy cow feed is also common practice, in amounts similar to that of plant-based dairy alternatives (~140 mg of minerals and 1 mg vitamin per 100 g milk) (Röös et al., 2015b). However, when 'processed' through the animal, the calcium fortified in the feed reaches a higher quality than the direct fortification in plant beverages.

Fortification and naturalness
When discussing fortification, the question of 'naturalness' often arises. 'Natural' is a term with highly positive connotations and is frequently used to label food products. To a large extent, the use and definition of the term natural is a philosophical question. Sandin (2017) points out that the term 'natural' is both vague and polysemous (several related meanings), which poses a challenge to anyone who wish to operationalise and define this term.

Challenges in developing fortification strategies

Weighting optimal nutrition of the individual against a level of adequate or 'good enough' nutrition for the many, for example in developing nutrient recommendations, is challenging. The requirement of any given nutrient is assumed to be normally distributed, meaning that if recommendations are set at the mean level of requirement, 50% of population would not have their nutrient requirements met at the recommended level of intake. The prevailing approach to this dilemma has been to add at least two standard deviations to the mean requirement and in that way include at least 95% of the population. However, different demographic groups have different nutritional requirements, so it has to be decided whether fortification programmes and nutritional and dietary recommendations should be designed to fit the most vulnerable, or the average population as a whole. For example, there is a large minority (women and girls of childbearing age) which has a larger iron requirement than the rest of the population, while at the same time there is a small minority (0.5%) which is especially sensitive to high iron intake (people with haemochromatosis). When considering these two groups simultaneously, should staple foods be fortified with iron? Another consideration is that the adverse effect of excess iron in the few people with haemochromatosis is far larger than the adverse effects of insufficient iron intake for many women and girls. Hence, it is not easy to decide which strategy is preferable, and different countries choose different strategies.

References to the appendices

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