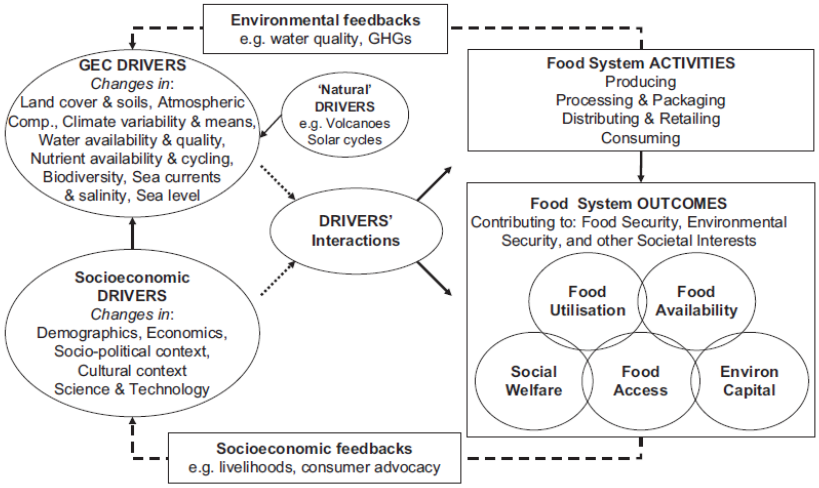
FOOD-ENVIRONMENT LINKS—MATCHING CARDIOVASCULAR HEALTH PROMOTION WITH A SUSTAINABLE FOOD SYSTEM

Dr Rebecca White, Environmental Change Institute, Oxford University, UK

1. Introduction

Food systems have multiple outcomes. Food security, diet-related health, and environmental sustainability (with its links into sufficient ecosystem service provision[1] and renewal) are three focussed on in this sub-chapter. But other important outcomes among which these sit (and sometimes compete) include profit, employment, cultural value and political-economic stability. Figure 30 shows a food systems framework which can be helpful as a way to conceptualise how these outcomes are linked to food system activities and drivers.[1]

Figure 30 Food systems, their drivers and feedbacks



Source: Ericksen, 2008.[1]

This framework shows how global environmental change is both a driver and an outcome of food systems. Food systems are seen as comprising 'food system activities' carried out by 'food system actors' which span the entire 'chain' (or cycle) from farm inputs, through to the acts of eating and throwing away food. This framework or approach reminds us that for many food supply chains there are multiple activities and powerful food system actors working between the agricultural stages of production and what is eaten by the final 'consumer'. Along with the consumer, they play an important part in driving food system change and shaping its environmental and health outcomes.

[1] Ecosystem services describe the ways humankind benefit from ecosystems. These are often grouped into four types – supporting (necessary for the production of other ecosystem services. Such as nutrient cycling and soil formation), provisioning (products obtained from ecosystems, like food, clean water and genetic resources), regulating (benefits obtained from regulation of ecosystem services, like carbon sequestration and waste decomposition) and cultural (non-material benefits obtained from ecosystems, like spiritual and cultural enrichment).

What constitutes a 'sustainable food system' or indeed a sustainable diet in the view of different food system actors will vary, and inevitably involve some trade-offs between different outcomes. This sub-chapter seeks to document the ways in which the food system links into and influences environmental outcomes, and the interactions between environmental and health outcomes. The environment is also changing in ways that affect food systems, with implications for diet and diet-related health. The sub-chapter reviews what we can confidently say about how environmental change may affect diets given the complicated pathways of causation between these elements of the food system. It then goes on to review what we know about policies and practices that are changing what food we consume in ways that promote both sustainability and health outcomes. It ends with some recommendations for next steps.

2. Impact of food systems on the environment

Food system activities, and particularly agriculture, have considerable environmental impact across a range of areas. These include huge alteration of nitrogen and phosphorous biogeochemical cycling[2] leading to algal blooms and eutrophication[3] of water courses,[2] the use of agrochemicals to manage pests with detrimental impacts on wildlife and pollinators,[3] climate change impacts, land-use change (with associated impacts on biodiversity), and water use. Here the latter three impacts are focussed on because researchers have been able to quantify them in association with food systems and the production of particular types of food, and in turn have explored the impacts of different dietary mixes.

2.1. Climate change, land use and biodiversity impacts

Globally food production and consumption contributed 19-29% of global greenhouse gas emissions in 2008.[4] Agriculture is responsible for the majority of food system emissions (80-86% according to Vermeulen et al in 2012[4]), although estimates of exact proportions vary according to the boundaries around what is included and excluded in the calculations. Figure 31 shows how this breaks down across different agricultural contributors and over time.[5]

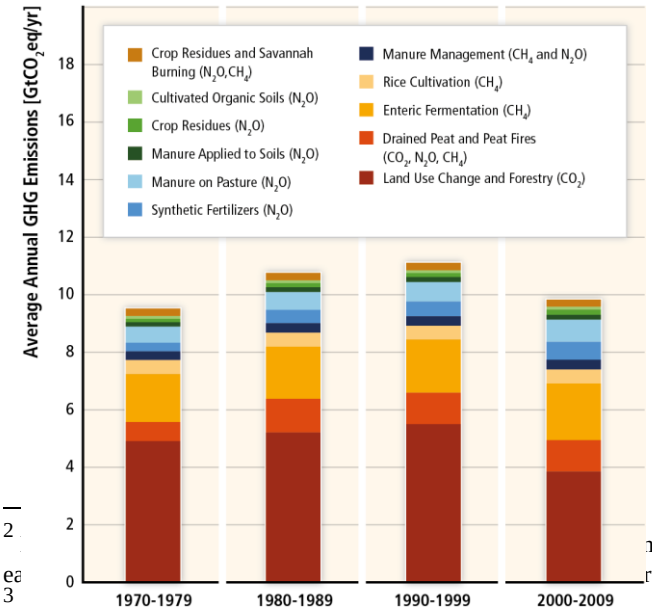


Figure 31 Change in Greenhouse Gas emissions over time from the agriculture sector globally
Source: IPCC, 2014[5]

Land use change (LUC) and forestry is a large contributor to the overall greenhouse gas (GHG) footprint of food as agriculture is a major driver of deforestation and LUC. In 2010 the amount of land needed to satisfy the EU's consumption of agricultural goods and services was 43% greater than the land available within its boundaries.[6] The suitability of land for agriculture seems to be a major

2
ea
3
nts through the living and non-living parts of the
rth system are all implicated in this cycling.
Eutrophication describes the process by which water becomes enriched with excessive amounts of nutrient, causing blooms of plant life, which affect light distribution in the water body and – when they die and decompose – depl
comm
rough changing the makeup of aquatic plant
ater body. Some blooms can also be toxic.

determinant of the intensity and extent of land use pressures globally.

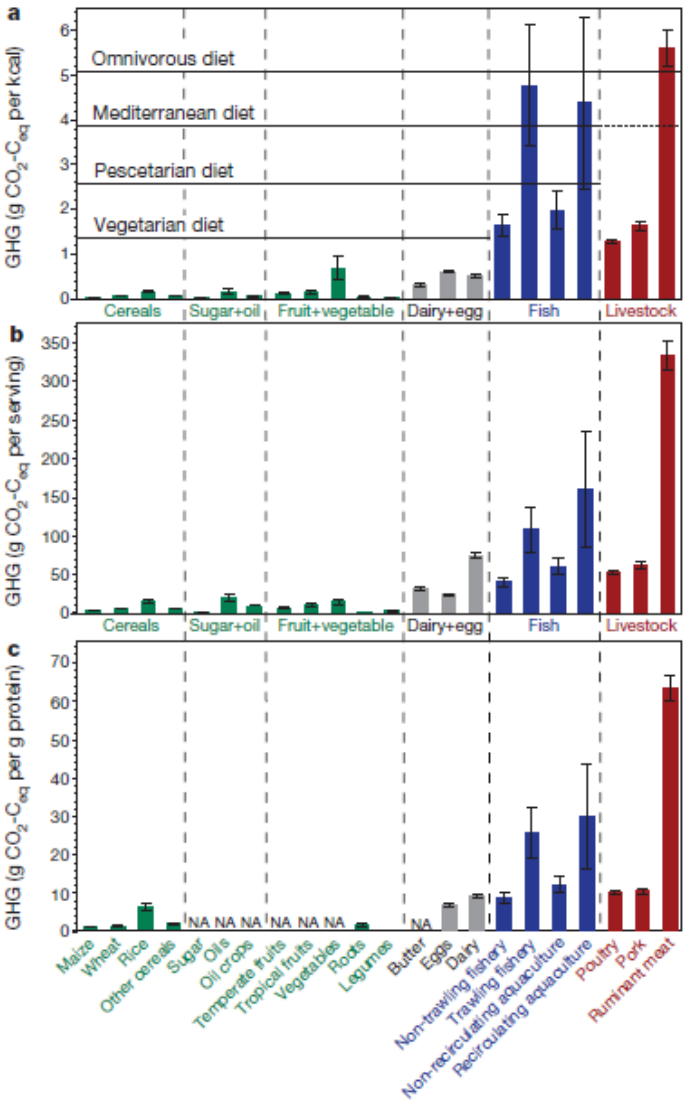
Tropical deforestation is the single largest threat to biodiversity in land-based ecosystems, in addition to impacts on the livelihoods of around 350 million people who rely on forests, and impacts on ecosystem services.[7] Looking at the possible drivers of deforestation, Defries et al in 2010[8] note the strongly significant correlation between forest loss and both urban growth rates and net agricultural trade per capita between 2000-2005. The latter is a particularly strong correlation in Asia, a major palm oil exporter. They suggest that, 'although these associations do not prove causality, the positive correlations do suggest that the traditional mode of clearing in frontier landscapes for small-scale production to support subsistence needs or local markets is no longer the dominant driver of deforestation in many places. Rather, our analysis indicates that higher rates of forest loss for 2000-2005 are strongly associated with demands for agricultural products in distant urban and international locations' (p. 178). Expanding oil crop planting was responsible for most agricultural land expansion between 1990-2005.[9] Increasing demand for oil crops—including palm oil—looks set to continue with end uses including direct dietary intake, oilseed cakes for livestock production and non-food uses such as cosmetics, paints, detergents, lubricants and biodiesel.[9]

Biodiversity impacts may be disproportionately large as pressures around LUC are particularly intense, widespread and intensifying in areas with high biodiversity (Venter et al 2016). Because yield increases in major cereal crops are not keeping pace with demand expected to 2050[10] then increases in the area of cropped land seem highly likely. FAO predict increases in cropped areas of land globally by 7% by 2030.[9] Through the development of integrated models, Delzeit et al [11] explored where this might take place globally, finding that while there was some variability in the kinds of areas into which croplands seemed likely to expand, overall, cropland expansion (given climate changes to suitability of land area) risked taking place in many regions that are valuable for biodiversity conservation.

Beyond agriculture other parts of the food system can also contribute significant greenhouse gas (GHG) emissions.

Figure 32 Lifecycle GHG emissions (CO2-Ceq) for 22 different food types. The data are based on an analysis of 555 food production systems: a) per kilocalorie; b) per United States Department of Agriculture (USDA)-defined serving; c) per gram of protein. The mean and Standard Error from the Mean (error bars) are shown for each case. NB. Because different food groups play different roles in the diet, it is most useful to look at the comparative GHG emissions per calorie for cereals (and any other food type eaten for calorific benefit), per serving for fruits and vegetables, and per g protein for animal products and legumes.

(Source: Tilman and Clark[13])



This is particularly the case in countries where high levels of food processing occur, food systems tend to be national/global in nature rather than local, high levels of food waste occur and there is a significant food service sector. In the UK it is estimated that agriculture contributes around 40% of the national 'food GHG footprint' with other contributions including manufacturing (12%), transport (12%), home storage and cooking (9%) and retail and catering (13%).[12]

Different food types and individual foodstuffs have different greenhouse gas 'footprints'. This derives from the specificities of their production process – e.g., resource demands for growth, transport mode, growing environment, storage requirements. The following discussion of greenhouse gas impacts and diet tries to draw generalisable lessons, despite the potential for variation more specifically.

Relative to animal-based foods, plant-based foods tend to have lower GHG emissions. This can be seen in Figure 32 comparing the GHG emissions of different food groups from Tilman and Clark.[13]

The generally lower GHG impacts of plant versus animal based foods is because it is more resource efficient to eat from a lower trophic level[4] (i.e. plants), than have to feed plants to animals and then eat the animals; livestock currently supply 13% of energy and 28% of the protein to the world's diet but consume half the world's production grains to do so (see IAASTD 2009 in Smith et al 2013,[14]). Furthermore, ruminant animals emit methane when feeding, making them additionally powerful emitters of greenhouse gases.

[4] Trophic level refers to the position of an organism in the biological food chain. Plants are seen as primary producers and at the first trophic level. Herbivores consume plants and are at the second trophic level. While omnivores/carnivores eat at the second and third trophic levels.

While poultry and pork have lower GHG impacts, they are commonly fed on grains which could otherwise be eaten by humans, while ruminants are able to digest grass and crop-residues therefore using grasslands and—where grazed sustainably—providing some cultural ecosystem services (e.g. maintaining grassland landscapes).[14]

So, environmental impacts depend on a number of factors: what livestock is raised; the conditions under which they are raised; the volume in which they are consumed; the relative importance placed on different environmental impacts they create (e.g. GHG emissions or land-use efficiency); and the opportunity costs and benefits they represent (e.g. how else might the land/grain/water they use be used, but, equally, would more fertiliser inputs be required in place of their waste).[15] If efficient land and resource use is a priority food system outcome in the European setting, it is interesting to note that the Health Council of the Netherlands estimates that 40-50% of existing livestock in Europe could be fed on natural grasslands and food industry waste products.[16]

In some circumstances livestock and ruminants in particular can be important contributors to food security, family asset management, livelihood opportunities and stability. They also help with nutrient cycling (e.g. providing nitrogen for crops) when part of mixed farming systems. So while there are clear environmental impacts of animal-based foods, careful *context-based* assessment is required regarding their 'sustainability'.

Another source of protein important to many diets globally, and in Europe, is fish. Figure 32 above shows that different sources and fishing techniques have different GHG impacts. Trawling fisheries have a high impact, in addition to having high levels of by-catch and, when bottom trawling, being destructive to ocean floor habitats.[17] Fishing in the ocean in general is being done to levels at (60%) or exceeding (30%), the level at which fish stocks have the capacity to recover.[17] Globally about half of all fish consumed are now farmed,[17] although in Europe it is 20%.[18] How and what is farmed also affects the environmental impact of this production method—while recirculating aquaculture has a higher GHG impact, its use of filtered water systems means much less water is used and pollution of this water can be better regulated.[19] In addition, farming of carnivorous or 'fed' fish (the dominant farmed aquatic food producing around 70% of aquaculture output, [17]) currently relies on by-catch/wild caught fish as a source of feed, making their production inextricably linked to sustainability issues in ocean fisheries. Farming of herbivorous fish and molluscs, and development of novel feedstuffs holds promise.

2.2. Water use impacts

Food production and consumption also relies on considerable water resources, with agriculture being the main water use activity in the food system (although processing and in-home use can be considerable too).[20] Agriculture is responsible for 70% of global freshwater withdrawals and more than 90% of its 'consumptive use'[21] – i.e. use of water that does not return to the land-based water environment for potential downstream use and is instead transpired.

A product's water footprint is defined as the total volume of freshwater used to produce a good. This can then be separated into blue, green and grey water, explained below (http://waterfootprint.org/en/water-footprint/what-is-water-footprint/).

	**Green water footprint** is water from precipitation that is stored in the root zone of the soil and evaporated, transpired or incorporated by plants. It is particularly relevant for agricultural, horticultural and forestry products.
	**Blue water footprint** is water that has been sourced from surface or groundwater resources and is either evaporated, incorporated into a product or taken from one body of water and returned to another, or returned at a different time. Irrigated agriculture, industry and domestic water use can each have a blue water footprint
	Grey water footprint is the amount of fresh water required to assimilate pollutants to meet specific water quality standards. The grey water footprint considers point-source pollution discharged to a freshwater resource directly through a pipe or indirectly through runoff or leaching from the soil, impervious surfaces, or other diffuse sources.

Given that using large quantities of water is only an issue if that resource is scarce locally, a further disaggregation of the footprint approach looks at 'blue water scarcity'. This is a more geographically specific measure and links blue water volume available with the human demand on that water in that locale. This 'stress weighted water usage' shows whether products use water in ways that increase scarcity.

The production of meat and dairy products requires a lot of water, again due to the relative inefficiency of converting feed into animal protein. Annex 2, taken from Mekonnen and Hoekstra,[20] illustrates the range of estimated water footprints for different food goods. Given this, a number of studies have looked at the water impacts of reducing or removing meat and dairy from the diet. A review of five studies looking at vegetarian diets (three European and two Californian) in Hess and colleagues in 2015 shows reductions in the overall water footprint of between 33-66% compared to reference diets.[22] However, Meier and Christen in 2013 find that blue water use increased by 85% in their vegetarian diet and 107% in their vegan diet because they assumed a significant increase in consumption of nuts and seeds for these diets.[23] These are grown in areas with low rainfall and high reliance on stored water sources, and hence the high blue water footprint.

While, on the whole, studies comparing 'healthy' (following dietary recommendations) and reference diets show a decreased water footprint for the healthy diet, the extent to which this is the case varies. This is because results are sensitive to what is measured (total water footprint vs. blue water footprint or blue water scarcity), and the assumptions regarding exactly what is eaten in different diets compared to a reference. While Vanham[24] finds a 23% reduction in overall water use when following the German Nutrition Society recommendations compared to the baseline, and Meier and Christen[23] find a ~27% reduction in blue water use following the German Nutrition Society and the Federation for Independent Health Consultation, Hess et al[22] find only a 2.5% reduction in blue water use for a UK diet following the Eatwell plate. The relatively small reduction from Hess's research seems to arise from an increased consumption of rice, fruit and vegetables imported from water scarce areas, and increased milk consumption compared to the reference. This highlights the importance of accounting for where products are grown/ raised, as well as the products themselves.

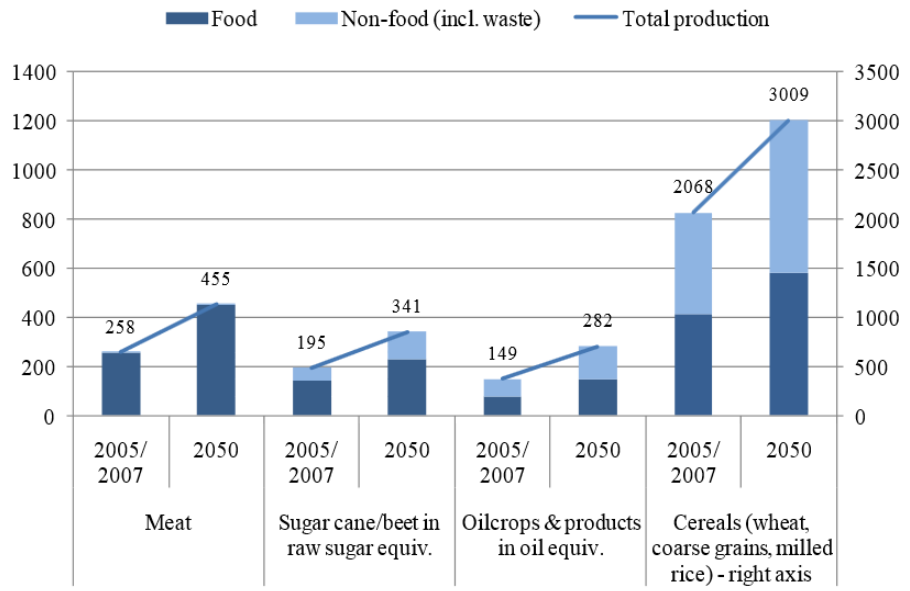
2.3. Waste

It is estimated that about one third of all food produced for human consumption is wasted, representing not only a lost opportunity for consumption but also unnecessary use of resources. Per capita food losses in Europe and North America are in the region of 280-300 kg/year, while in sub-Saharan Africa and South/Southeast Asia it is 120-170 kg/year.[25] The proportions arising from different stages of the food supply-consumption chain vary from place to place too—more is lost from early and middle stages in low-income countries, while industrialised countries waste more at the consumer and retail stages.

2.4. Trends

Trends in terms of population increase, and changes to diets globally, suggest that the demand for food, across commodity groups, will increase in the future (see Figure 33). Assumed dietary changes, often encapsulated by the 'nutrition transition' include increased meat consumption, increased consumption of refined sugars, fats, oils, processed foods and alcohol, increased calorie intake and reduced consumption of fruits, vegetables, coarse grains and tubers.[26,27] These trends are linked to increased incomes in low- and middle-income countries, urbanisation, globalisation and cultural homogenisation, and technological diffusion.

Figure 33 Predicted changes in world production and use of major products (millions of tonnes)



From a dietary perspective, Tilman and Clark in 2014 point out that, 'if we look at trends in dietary change with forecasts of per capita income to 2050, relative to 2009, it is predicted that in 2050 global average per capita income-dependent diet would have 15% more total calories and 11% more total protein, 61% more empty calories, 18% fewer servings of fruits and vegetables, 2.7% less plant protein, 23% more pork and poultry, 31% more ruminant meat, 58% more dairy and eggs, and 82% more fish and seafood'.[13]

While there has been some decoupling of GHG emissions from food production[5] at the agricultural stages between 1970 and 2007, with emissions per unit of product declining by 39% and 44% for crop and livestock production respectively, efficiency gains in GHG emissions have not kept pace with the larger increase in demand. Crop and livestock production have increased by 118% and 102% in that time, respectively.[28]

Using Life Cycle Assessment (LCA) emissions data Tilman and Clark calculated annual per capita GHG emissions from food production at the farming stage alone for an average global diet in 2009, and then for the global-average income-dependent diet[6] projected to 2050.[13] Combined with global population projections of 36% increase to 2050, the net effect is an estimated 80% increase in global GHG emissions from food production (from 2.27 to 4.1Gt/Yr of CO2e). Note this may be slightly tempered if the efficiency improvements characterised by Bennetzen et al continue.[28] Nevertheless, global aspirations to prevent greenhouse gas emissions exceeding levels linked to more than 2°C warming require net zero emissions globally by 2100.[29] While it is recognised that the agricultural sector cannot fully decarbonise, this increasing trend presents a serious problem requiring technologically complex net negative emissions from other sectors to compensate. Water and land-use demands will also increase, suggesting even further pressure on the natural resources underpinning our food production systems into the future.

2.5. Impact of food systems on the environment: conclusions and key messages

- Food based GHG emissions contribute 19-29% of emissions globally. This may increase by around 80% to 2050 given current global trends. This makes the already extremely challenging target of achieving net zero GHG emissions by 2100—as set out in the Paris Climate Change Agreement—even more difficult.
- Relative to animal-based foods, plant-based foods tend to have far lower GHG emissions. This is because it is generally more resource efficient to eat from a lower trophic level (i.e. plants), than have to feed plants to animals and then eat the animals. On the whole, animal based foods also have higher water footprints than plant-based foods.
- The impact of high water use is determined by local water scarcity. Environmental impacts and other food system outcomes from animal rearing also depend on how animals are raised, and the local economic role of livestock. This suggests that *to a degree* the overall sustainability impact of animal based foods is geographically and practice dependent.
- Trends globally are towards higher levels of meat and animal product consumption.
- It is important that what we eat, particularly in Europe, becomes part of the discourse around achieving our climate commitments.

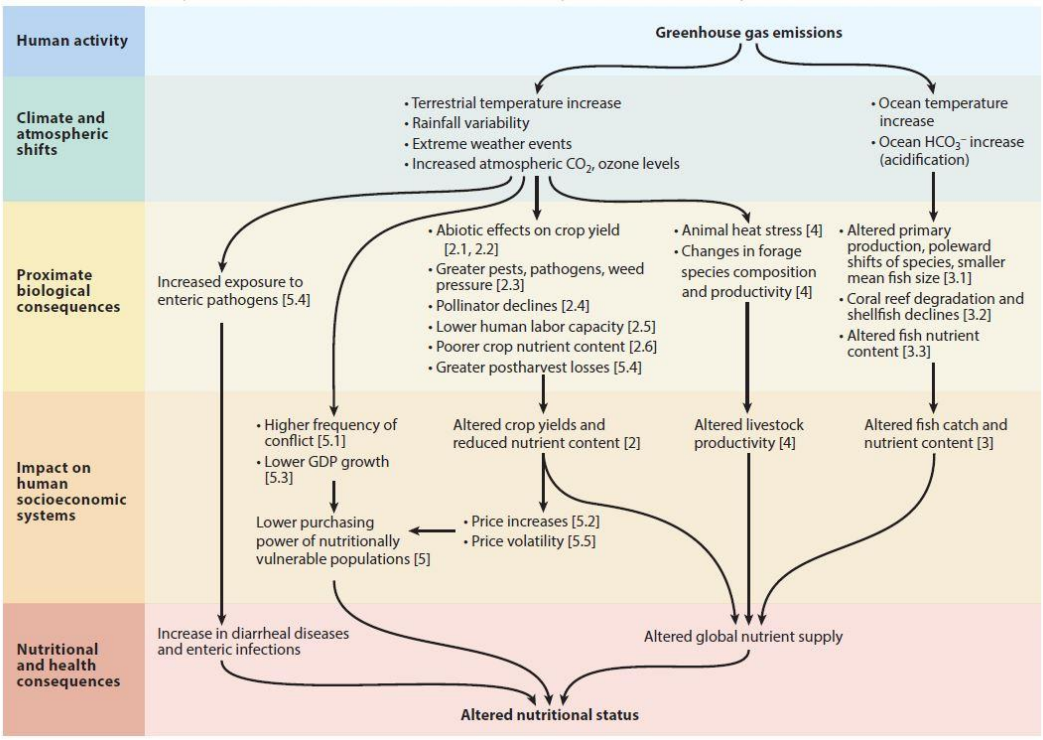
[5] That is a weakening of the strength of the relationship between greenhouse gas emission creation and agricultural food production.

[6] Because diets globally tend to change quite predictably, for key indicators, as income increases, it was possible to model a future 'income dependent diet' based on assumptions of how incomes would increase into the future.

3. Impact of predicted environmental changes on diet and diet-related health

Determining the impact of predicted environmental changes on diet and thus diet-related health involves a pathway of causality which can be quite hard to untangle and attribute. And as Nelson *et al* note in reference to linking climate change and food security outcomes, 'combined biophysical-socioeconomic modelling of this detail and extent is still in its infancy'.[30] Figure 34 below traces out just some of the ways in which climate change in particular links to altered nutritional status.[31] Not included in this diagram are the myriad ways in which climate change may affect diet and diet related health beyond just price impacts—for example around extreme weather events affecting logistics; increased cold storage demands under higher ambient temperatures; and increased food safety concerns with higher ambient temperatures (bacteria and mycotoxins).[32]

Figure 34 Pathways for impacts of climate change on food systems, food security, and undernutrition



Source: Myers el al, 2014 [33]

The degree of agricultural and food system adaptation will also define the ultimate impacts of environmental change—for example, Challinor et al, in a meta-analysis of studies on climate change-yield links published in 2014, found yields were 7-15% higher with adaptation than without it.[34]

Myers et al, in their 2017 review of studies looking at climate change and food security, also outline potential impacts of climate change on wild fish catch.[33] A study quoted by Cheung et al suggests potential global reductions in catch by 3-13% on average under a high emissions scenario, but with spatial variability; some regions

may experience 30-60% reductions.[35] The impacts on aquaculture are less clear, and may even see increases in production in some areas as sea ice recedes and fish potentially grow faster in warmer conditions. Altogether the complexity of marine ecosystems and their interactions with climate change make this a highly uncertain field to model.

But how much changes in production/catch affect the final retail price of food will depend on the proportion of final end-price comprising the cost of the commodity. Other influential factors will include the nature of local markets, the degree of processing and other added value etc. (which may also be affected by environmental change, e.g., cost and availability of water for processing or cleaning) and the ways in which environmental change affects physical access to food and markets (e.g., localised flooding, or food spoilage through heat-related power cuts). Knock-on implications for diet-related health will depend on what foodstuffs make up the diet and how people adapt.

Elevated ambient CO_2 levels also affect the nutritional composition of crops. In field-grown crop experiments by Myers and colleagues some C_3 crops – wheat, rice, field peas and soybeans – were found to have lower concentrations of iron and zinc with elevated CO_2 (around 3-10%).[31] Protein levels were also reduced in wheat and rice (6.3% in wheat and 7.8% in rice).[31] For those relying on these crops as a significant source of dietary zinc, iron and protein in the future, this presents an increased risk of deficiencies in populations already vulnerable to undernutrition (in 2010 about 2.3 billion people were living in countries whose populations received at least 60% of their dietary zinc and/or iron from C_3 grains and legumes).

Different groups of people will also be affected differently—where there is direct reliance on crops, such as in subsistence systems, diet and diet-related health may be directly affected by detrimental changes in the biophysical environment. Price increases may benefit those who sell agricultural products. Where people rely on local and non-integrated markets (i.e. there is little flow of goods between markets), again, changes in food production due to environmental changes will be more strongly reflected in changes to the diet. However, where people rely on food bought in globally integrated markets, the impact of environmental change on diet will be more difficult to predict given the substitutability of products and growing areas. Finally, purchasing power, and how this changes over time and alongside the environment, will mediate the sensitivity of people to changes in food prices.

What research has been done looking at the potential for future environmental change to influence food security has focussed on climate change specifically, and is biased towards impacts at the agricultural stage and towards quantifying impacts on food price and calorie availability (rather than looking at other aspects of what comprises food security such as physical access, safety, suitability, micronutrient availability, etc.). Furthermore, 'substantial differences in projections of price, production, and land-use changes by different models exist, implying a high degree of model uncertainty and impact projections'.[32] In a systematic model comparison, a range of climate, crop and economic models were run with a high emissions climate scenario and a 'middle of the road' shared socioeconomic pathway to 2050. This found global average yield reductions of 11% and price increases of 20% compared to the baseline values for major crops.[36]

In an earlier study and using a single integrated model, Nelson et al determined in 2010 that prices would rise by between 31-106% by 2050 for wheat, rice and maize.[30] This range is caused by variations in assumptions regarding the amount of climate change mitigation, population and economic growth under different future scenarios. In terms of nutritional and human impact, under optimistic scenarios (higher GDP, lower population growth, higher climate change mitigation) there was an average 45% reduction (50% reduction in MICs and 37% reduction in LICs) in the number of malnourished children globally compared to the 2010 baseline. With a pessimistic scenario, the average reduction in the number of malnourished children achieved was 2%, representing a 10% reduction in MICs but an 18% increase in LICs.

For the reasons given above, linking environment or climate changes to *dietary changes* is highly complex. However, Springmann and colleagues have attempted this with a global modelling study focussed on potential changes to fresh fruit, vegetable and red meat production and then consumption under future climate change and socio-economic scenarios.[37] The consequent diet- and weight-related health impacts of this for populations in 155 world regions are also modelled. This study found that climate change (assuming a 'high emissions scenario') could lead to reductions in overall food production globally. Fruit and vegetable consumption was estimated to reduce by 4%, and red meat consumption by 0.7%. Through knock-on implications for undernutrition, dietary change and weight changes, it was estimated this would then lead to 529 000 climate related deaths worldwide by 2050.

The regional impacts are highly uneven however, with higher deaths in the western Pacific region in particular, but also south and central Asia, central Africa and the eastern Mediterranean and eastern Europe. The cause of death also varies—with changes in fruit and vegetable consumption responsible for about 550 000 additional deaths globally, and underweight about 250 000. This is slightly offset by reductions in deaths from red meat consumption, overweight and obesity of about 300 000 deaths. Again, how people are more or less likely to die varies regionally. Additional death from being underweight dominates in the LMICs of Africa, and is responsible for over half of additional deaths in the LMICs of Southeast Asia. While additional deaths from reduced fruit and vegetable consumption dominates in high-income countries and the LMICs of the Americas, eastern Mediterranean region, western Pacific region and Europe. The sensitivity analysis of this study suggests that climate change mitigation would greatly reduce this number of deaths.

3.1. Impact of predicted environmental changes on diet and diet-related health: conclusions and key messages:

- The 'pathway to impact' between future environmental change and dietary intake is extremely complex and is strongly mediated by future population, economic, trade and cultural change.
- Beyond studies looking at changes to caloric intake with climate change, there is very little research linking a changing climate to dietary impacts. There is virtually no research looking at how environmental change more broadly may impact on diets in the future.
- Modelling research suggests that climate change will have negative implications for diet-related health overall, due to reductions in calorie intake

for poorer populations and reductions in fruit and vegetable consumption for wealthier people.

4. Identification of ideal dietary patterns that satisfy health and sustainability criteria

There is now a reasonable body of evidence exploring dietary patterns that satisfy both health and *some* sustainability criteria – again, with an emphasis on GHG emissions, but also land and water use. Some of the evidence in support of this is reviewed before outlining proposed 'ideal dietary patterns'.

Tilman et al conducted a meta-analysis of research and compared 'emerging global diets' with three 'well studied' diets.[13] Altogether 10 million person-years of observation, across eight study cohorts were amassed to compare disease incidence rates and environmental impacts between these diets.

The diets studied were defined as follows:
'Emerging global diet' – typical omnivorous diet used in the cohort studies reviewed for comparison with alternative diet.
Mediterranean – rich in vegetables and fruit, seafood and includes grains, sugars, oils, eggs, dairy and moderate amounts of poultry, pork, lamb and beef.
Pescetarian – vegetarian diet and seafood.
Vegetarian – grains, vegetables, fruits, sugars, oils, eggs and dairy, and generally not more than one serving per month of meat or seafood.

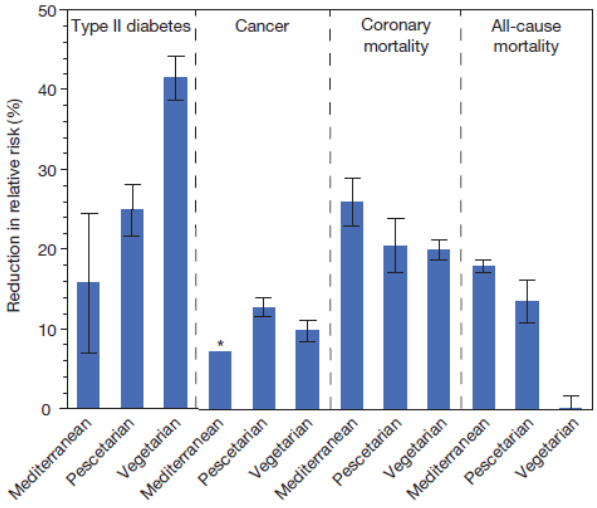


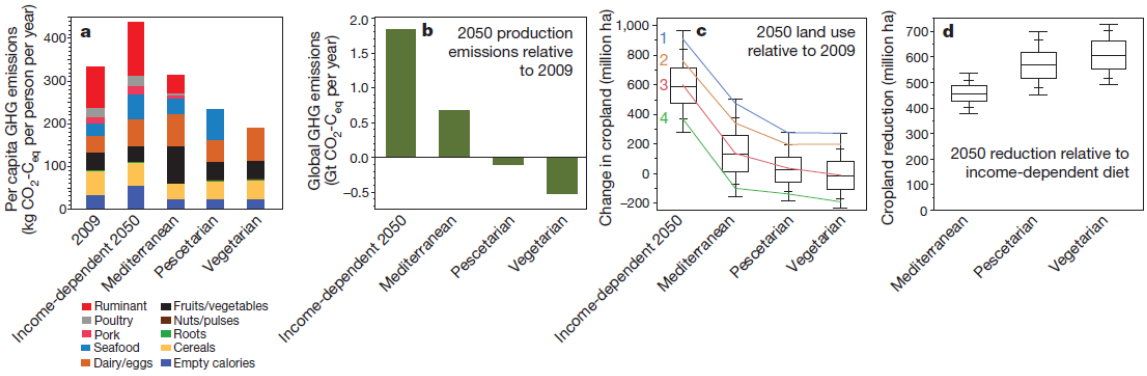
Figure 35 Diet dependent percentage reductions in relative risk of type II diabetes, cancer, coronary heart disease mortality and of all-cause mortality when comparing each alternative diet. * Cancer from Mediterranean diets is from a single study so no s.e.m is shown.

Source: Tilman and Clark, 2014 [13]

Figure 35 shows a reduction in the relative risk of type II diabetes, cancer, coronary mortality and all-cause mortality (except for vegetarianism) in the three alternative diets compared to the 'global diet' baseline.

The GHG emissions and land-use implications of the different diets were also compared, including against a projected, 'income-dependent 2050' diet which assumes an increase in the number of people globally eating more 'westernised' diets. The results, as shown in Figure 36, clearly show the considerable differences between GHG emissions for the different diets, which looking to 2050 would lead to considerable savings in GHG emissions and land use with eating Mediterranean, pescetarian and especially vegetarian diets. For the latter two diets, emissions would be net negative despite large rises in population by 2050.

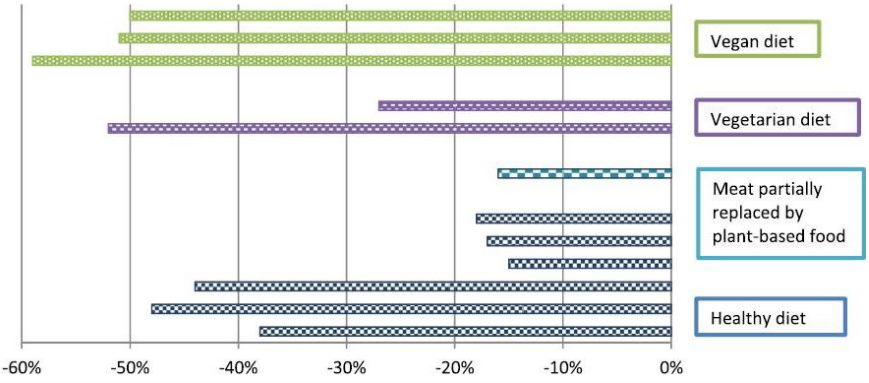
Figure 36 Effect of diets on GHG emissions and cropland. a) per capita food production GHG emissions for five diets, b) forecasted 2009 to 2050 changes (2009 set to 0) in global food emissions, and c) cropland area used for each diet. d) 2050 global cropland reductions from alternative diets relative to the income dependent diet. The box and whiskers plots show mean and percentiles below (2.5th, 10th, 25th) and above it (75th, 90th, 97.5th) based on 243 scenarios



Source: Tilman and Clark, 2014 [13]

In a systematic review of studies comparing the GHG and land-use impacts of different diets, Hallström et al found the following reductions in land-use across four studies reviewed, in percentage of relative change in land demand compared to reference scenarios.[38]

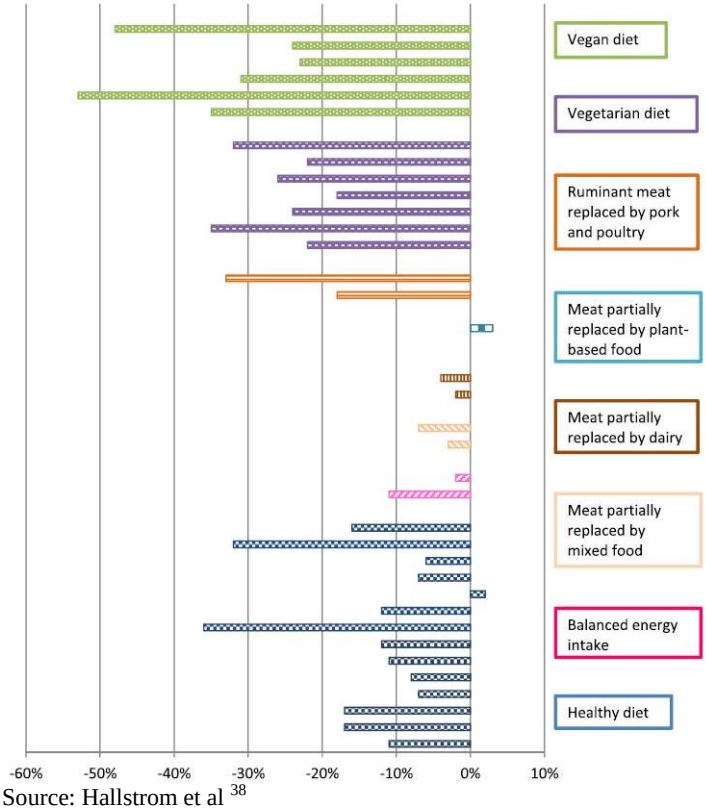
Figure 37 Impact of dietary change on current demand of land from the diet, in % of relative change in land demand compared to the reference scenarios. Data presented are from four articles



Source: Hallstrom et al [38]

And the following changes in GHG emissions from 12 articles reviewed – again, in percentage of relative change in GHG emissions compared to the reference scenarios.

Figure 38 Impact of dietary change on GHG emissions from diet, in % of relative change in GHG emissions compared to the reference scenarios. Results drawn from 12 articles



Source: Hallstrom et al [38]

It is worth noting that emissions are not always reduced by reducing meat consumption or following healthy guidelines. Some studies – Tom et al[39] and Vieux et al[40] – finding emission increases when following guidelines for a healthy diet. This is a matter of understanding both the nature and 'quality' of baseline existing diets in addition to what 'healthy' means in different countries. In the case of the Tom et al study, the guidelines were the USDA dietary recommendations which advise unusually high dairy consumption compared to many other national dietary guidelines. Equally, very large reductions in the consumption of added sugars is required compared to the baseline American diet, which do not have a large GHG footprint. In part this was then to be replaced by fruit (with considerably higher GHG impacts). To meet these guidelines Americans would need to increase their caloric intake from fruits, vegetables and dairy by 96, 104 and 204 calories daily. The Vieux study similarly had healthy diets that were lower in ruminant meat but higher in dairy, but with similar levels of pork, chicken and egg consumption to 'unhealthy' diets.[40] Here, sugary foods in the unhealthy diets were replaced by high levels of fruit and vegetable consumption. The emissions associated with fruits and vegetables depend on the degree to which they are grown in protected settings, eaten out of season, transported long distances and cold stored etc.

The review of water use implications of food, and of different diets, in section 3.4.2.2, also highlights that while low-meat and 'healthy' diets can have lower water and blue-water footprints, this is not always born out. Substitution of 'unhealthy' foods with high water footprint foods such as rice, fruits and dairy, will lessen (or indeed reverse) any potential savings.

Altogether, this suggests that while following a 'healthy' diet according to national guidelines does not automatically mean reductions in the GHG, land-use and water

impacts of that diet, there are considerable reductions possible if a low-meat and healthy diet is consumed via particular types of food. Where there is a potential clash is around the consumption of fish and oily fish given already high levels of fish stock exploitation, and high interdependence between farmed and wild fish stocks. Highly intensive animal rearing practices can also have lower GHG impacts per unit produced, but have poorer animal welfare outcomes.

An internationally accepted definition of a 'sustainable healthy eating pattern' does not exist, but Garnett and colleagues suggest in 2015 that there is increasingly an understanding of what these look like (based on existing research which tends to see sustainability as environmental, and within that emphasising GHG emissions, energy use and to a lesser extent water use.[41] Socio-economic or animal welfare aspects are not included). Broad principles for a healthy and sustainable diet are that they should be:

- Diverse in the energy density of foods (a mixture of some foods that have relatively few calories gram and some that are more energy dense)
- Low in animal products with all parts of the animal eaten
- Fish and fish related products eaten in moderation
- High in minimally processed, robust (i.e., products that have a longer shelf life and do not rely on excessive packaging or energy intensive storage conditions in order to be successfully transported and sold at retail), field-grown vegetables and in fruits
- Rich in whole-grains, tubers and legumes
- Low in processed foods high in fat, sugar and salt

Micronutrient deficiencies are a risk in some contexts, so reducing meat intake needs to be matched with careful increases in quantity and diversity of whole grains, legumes, fruits and vegetables. What this will look like in terms of actual foodstuffs eaten will vary from place to place according to what is able to be grown/ caught locally in an ecologically sound manner.

An example of expert-based dietary guidelines addressing both the healthiness and environmental sustainability of diets is the Swedish dietary guidelines published in 2015 (Livsmedelsverket 2015), which can be summarised as:

- Eat lots of fruit, vegetables and berries - high fibre vegetables such as root vegetables, cabbage, cauliflower, broccoli, beans and onions are an eco-friendly choice with less environmental impact than salad greens
- Eat fish and shellfish two to three times a week – vary the type of fish and look for products with sustainability labels
- Exercise at least 30 minutes every day
- Switch to whole grain for pasta, bread and cereals – all cereals have low carbon footprints and pesticide use is low. Rice is one of the crops with causing the most GHG emissions, so other grains and potatoes are a better choice for the environment
- Choose healthy fats like rape seed oil – rapeseed oil and olive oil generally have less of an impact on the environment than palm oil, while butter has a higher carbon footprint than vegetable oil but can help bring about a rich agricultural landscape and biodiversity

- Choose low fat, un-sweetened dairy products fortified with vitamin D. Methane from cows affect the climate. Therefore do not consume too much cheese and other dairy products; 0.2-0.5 litres of milk (not including cheese) a day is enough for calcium. However, cows can contribute to biodiversity conservation through the grazing of pastures
- Eat less red and processed meat – a maximum of 500 g red and processed meat per week (no limitation on chicken or other white meat) – meat is the food product that affects the climate and the environment the most, and it is therefore important to consume less
- Choose foods with less salt
- Reduce intake of sweets, cake, ice cream and other sugary foods – these unnecessary food cause environmental impact can contain lots of calories but hardly any nutrients
- Try to find your energy balance by eating just enough.[42]

The Dutch dietary guidelines, published in 2015, also seek to take advantage of the synergies between a healthy and sustainable dietary pattern. They have the following key messages, as summarised by the FAO:

- Follow a dietary pattern that involves eating more plant-based and less animal-based food, as recommended in the guidelines
- Eat at least 200 grams of vegetables and at least 200 grams of fruit daily
- Eat at least 90 grams of brown bread, wholemeal bread or other wholegrain products daily
- Eat legumes weekly
- Eat at least 15 grams of unsalted nuts daily
- Take a few portions of dairy produce daily, including milk or yogurt
- Eat one serving of fish weekly, preferably oily fish
- Drink three cups of tea daily
- Replace refined cereal products by whole-grain products
- Replace butter, hard margarines, and cooking fats by soft margarines, liquid cooking fats, and vegetable oils
- Replace unfiltered coffee by filtered coffee
- Limit the consumption of red meat, particularly processed meat
- Minimise consumption of sugar-containing beverages
- Don´t drink alcohol or no more than one glass daily
- Limit salt intake to 6 grams daily
- Nutrient supplements are not needed, except for specific groups for which supplementation applies.[43]

The DEFRA publication and Swedish guidelines note the importance of eating seasonal and sustainably caught fish.[43,44] This is an area where there is a potential discordance between healthy eating guidelines and environmental outcomes. Many healthy eating guidelines suggest fish consumption above current levels, and given global fish stocks are already highly vulnerable to exploitation, meeting this healthy eating target has environmental trade-offs. However, it is interesting to note that the Dutch guidelines now recommend only one portion of fish a week, compared to two in its previously published guidelines and two to three portions in the Swedish guidelines.

4.1. Identification of ideal dietary patterns that satisfy health and sustainability criteria: conclusions and key messages

- Encouragingly there is considerable overlap between consuming 'healthy, lower meat diets' and achieving higher levels of sustainability as defined by GHG emissions, land-use and water use.
- However, clear guidance would be needed to ensure that nutritional demands are met while achieving better sustainability outcomes; there is the potential for poorer sustainability outcomes when some foods are substituted into the diet.
- There is a lack of research looking at healthier, low meat diets and wider indicators of environmental sustainability such as biodiversity impacts, nitrogen and phosphorous use, pollinator impacts, etc. (Although there is no obvious reason to think that results would look significantly different when considering these other impacts. It seems more likely they would provide a more nuanced picture rather than a different one).
- There is a lack of research on the implications of a low meat and healthy diet for the socio-economic aspects of sustainability (such as equity or livelihood impacts).

5. Existing proposed policy solutions to health-environment issues around food, and evidence to justify approaches

Very few policy solutions bridge the health and environment impacts of food at present. As noted above, some dietary guidelines—including those for Sweden, the Netherlands, Germany, Australia, Brazil and the Nordic countries—have incorporated sustainability criteria to a greater or lesser extent. These, along with an exploration of other interventions that can be used to shift diets towards healthier and more sustainable eating patterns, will be briefly discussed here. This review will heavily draw from Garnett and colleagues who reviewed policies and actions to shift eating patterns towards better health and sustainability outcomes.[41]

Combining health and sustainability in dietary guidelines is a significant development in this field. There is potential to reach a wider audience for dietary guidelines, with different motivations to act on those guidelines, by integrating sustainability issues.

While health professionals may know the content of dietary guidelines well, if they are to effectively and confidently to communicate these, knowledge of the evidence behind such messages is required. However, Murphy suggests this is 'less well established' amongst UK health professionals than knowledge of the guidelines themselves. The complexities associated with health-environment links would need to be understood in the case of effective healthy and sustainable eating guidelines.[45]

In addition, while 100% of participants in a questionnaire conducted by Rooney et al (2013) knew of the 5-a day guideline on fruit and vegetable consumption in the UK,[46] over 60% of adults do not meet this target in the UK.[47] So, there is considerable evidence of the knowledge-action gap when it comes to eating behaviours (as well as environmentally motivated behaviours).

As well as being a pre-cursor for action, knowledge among the general public may be an important basis for governments, public health bodies and companies being able

successfully to introduce new policies. While evidence from a six-country European survey[7] suggests there is quite good knowledge of nutrition such as what should be eaten often, a bit and rarely, knowledge around different types of fat and consumption of red meat was limited.[48] In terms of environmental knowledge on food, an 18 country survey[849] found that while people generally believed significant change is needed to improve the sustainability of the food system, they felt personally alienated and powerless to make changes. There was also little understanding of the links between meat production/consumption and environmental impacts. However, the context may be shifting in some countries, with a 2013 YouGov poll in the UK finding 31% of respondents knowing that there are significant environmental impacts from producing meat, up from 14% in 2007.[50] The most significant change in knowledge was seen among younger respondents.

Research to evaluate the understanding among the general populace of health-environment links, as well as the cultural and identity based roles of particular products in the diet, is in its infancy. As Macdiarmid and colleagues note, 'studies have modelled 'ideal' sustainable diets based on objective criteria for environmental and nutritional goals but as yet few have fully taken account of the social world of eating, with personal and cultural acceptability of dietary choices'.[51] The role of, for example meat, in the diet is likely to be highly culturally specific also, suggesting engagement on the issue needs nuance and sensitivity.

Openness to the idea of reducing meat consumption is limited. In the YouGov survey in the UK mentioned earlier, only one third of respondents said they would be willing to *consider* reducing their meat consumption,[50] while a quarter of the respondents had already cut back on meat consumption (mainly for health and economic reasons). In a focus group study with 87 participants from NE Scotland (one of which was vegetarian and three were ex-vegetarian), three dominant themes appeared: 1. Lack of awareness between meat consumption and climate change; 2. Perceptions that personal meat consumption plays a minimal role in the global context of climate change; 3. Resistance to the idea of reducing personal meat consumption. The latter theme was found to prevail across men and women, socio-economic group, and urban/rural location.[51]

In addition to the need to build the knowledge base, is an acceptance that for systemic change of the scale required, we need to focus beyond the individual and beyond traditional 'rational actor' models as the locus and means of action. This requires engagement with all stages of the supply chain and beyond that with the macroeconomic policies that form the institutional architecture within which companies operate and trade is shaped.

Garnett et al conducted a review of possible policies and actions to shift eating patterns towards more healthy and sustainable outcomes.[41] Some aspects of that review are very briefly summarised in Table 8.

Table 8 Shifting eating patterns towards more healthy and sustainable outcomes

[7] UK, Sweden, France, Germany, Poland and Hungary.

[8] Britain, Sweden, Canada, Australia, America, Japan, France, Hungary, Germany, Spain, South Africa, South Korea, Argentina, Mexico, Brazil, Russia, China, India.

1	Disincentivise or incentivise choices through fiscal measures. E.g. Taxes, subsidies or trading.
Efficacy in changing production and consumption of sustainable and healthy foods	
Although there is an emerging body of evidence on use of health-related food taxes, there are currently no taxes or subsidies that target both environment and health. It is not clear how supply chains would react to the imposition of a tax and there is a lack of research into substitution behaviour, leakage and the rebound effect[9] on other environment/ health outcomes. The cross-issue impacts of fiscal measures aimed at either environment or health need better researching but some environment-tax studies find the lower GHG impact of sugars can lead to perverse health outcomes.	
2	Change the governance of production or consumption E.g. Macroeconomic policies or agreements, national public procurement, planning policies & other regulations
Efficacy in changing production and consumption of sustainable and healthy foods	
Macro-economic policies (e.g. trade, liberalisation, foreign direct investment, national R&D strategies) are strongly implicated in the nutrition transition suggesting they are a powerful driver of change. Beyond agricultural subsidies there have been no attempts to date to change macroeconomic policy towards environment or health ends relating to food specifically. We need a much better understanding of what this macro-economic intervention might look like while appreciating that directly linking policies to better outcomes for health and environment may be difficult given the complex ways this scale of policy creates impact. Research exploring planning policies, consumption patterns and environment outcomes has not been done. But there are a number of studies showing how planning can influence more generally healthy and sustainable behaviours.	
3	Encourage collaboration and shared agreements E.g. Voluntary industry agreements and certification schemes
Efficacy in changing production and consumption of sustainable and healthy foods	
Reviews have found that, if properly implemented and monitored, businesses can aid in achieving policy aims through voluntary agreements. But because they tend to take the place of regulatory alternatives, it is difficult to ascertain their relative effectiveness or strength. Similarly determining whether voluntary agreement actions are additional to what might have happened anyway is difficult. Significant disincentives for non-participation and sanctions for non-compliance are found in some of the most effective voluntary agreements. Proposed actions need to be evidence-based, well defined, measurable and additional. A follow up to the current environmental voluntary agreement in the UK – Courtauld 2025 – seems likely to include some focus on healthy sustainable eating. Certification can shift markets, but evidence of measurable benefits on the environment is more mixed. Market for certified products is fairly weak, but can work with policy to raise standards – e.g., public procurement of good certification scheme products. Policies are needed to ensure certification works well – improve transparency, enable access and ensure robust monitoring. Policy also needs to work beyond certification in setting standards for levels of consumption.	
4	Changing the context, defaults and norms of production and consumption. E.g. Changing choice architecture, nudge, store layouts, catering provision, reformulation etc.
Efficacy in changing production and consumption of sustainable and healthy foods	
Interventions linked to 'nudge' approaches in supermarkets, schools and workplaces can be somewhat effective when a mixture is used, often with a fiscal component. When a mixture of more active interventions was compared with passive information provision, the former was found to be more effective. In general, nudge interventions have limited robust evidence though. More research is needed, especially on the longevity of effects. Nudge 'cannot be seen as a substitute for regulatory or fiscal interventions' (ditto certification).	
5	Inform, educate, promote or empower through community initiatives, labelling and other means. E.g. Labelling, gardening or cooking projects, media or other campaigns, education programmes.
Efficacy in changing production and consumption of sustainable and healthy foods	
This politically-acceptable approach has been the backbone of health promotion policy in recent years, but—as discussed elsewhere in this paper— has been of limited effectiveness. The impact of labelling is 'weakly positive', but is not always understood and is used more by more concerned people. However, it may 'soften up' the public to more 'interventionist approaches'. It may also promote a	

[9] Substitution describes what people who change consumption behaviour because of a tax buy instead. Leakage describes the potential for companies to export more of their product to non-taxing countries and so just geographically displace impact rather than reduce it. The rebound effect, more traditionally used in energy studies, describes how people spend any saved money (e.g. by reducing their meat consumption) in other areas of their life and the potential for them to spend saved money on equally or more greenhouse gas intensive activities.

'race to the top' by companies, especially with benchmarking by NGOs. On the environment, knowledge and desire for it is relatively low among consumers. Community initiatives – evidence for impact is weak, reflecting difficulty of and low levels of evaluation. May have constructive role to play in consumer engagement.

Source: Adapted from Garnett et al[41]

One recent US-UK initiative (launched mid 2016 by the World Resources Institute) is the Better Buying Lab, which is undertaking research in partnership with a range of large companies into how to shift people's purchasing habits towards healthier and sustainable diets (in its first phase this is framed as increasing the purchase of plant-based food). It will be interesting to see what this partnership achieves and finds.

Finally, it is worth noting that at the macro-policy level, the Paris Climate Change Agreement coupled with the Sustainable Development Goals provide an important pair of policy drivers for encouraging a more serious and integrated look at health-environment issues. While agriculture is only indirectly included in the Paris Climate Change Agreement, the huge contribution of agriculture to global GHG emissions and the implications of omitting this sector altogether from mitigation efforts for what other sectors need to achieve, suggests that where 'wins' are available they need to be taken. The range of the 17 SDGs linked to environment, diet, health and hunger (2: zero hunger; 3: good health and wellbeing; 6: clean water and sanitation; 11: sustainable cities and communities; 12: responsible consumption and production; 13: climate action; 14: life below water, 15: life on land) highlight that seeking to achieve these goals individually and without looking at interactions between them would be folly. The question now is, 'how do we move forward with doing this?'

5.1. Existing proposed policy solutions to health-environment issues: conclusions and key messages

- There are some pioneering examples of integrating health and environmental outcomes in food system interventions, such as around dietary guidelines and engaging public institutions. But examples are still few and far between.
- There have been some important advances around the Paris Climate Change Agreement and the Sustainable Development Goals which provide an opportunity to promote an integrated approach to health-environment interactions.
- There is currently too much focus on passive information based approaches to seeking to shift the health and environmental food consumption behaviours of people.
- A large range of interventions will be needed to shift diets towards healthier and more sustainable outcomes, including more active forms of intervention, and at a range of levels – people, institutions, regions, economies and global political-economic regimes. In particular, more research and action is needed regarding interventions at the macro-economic level.
- There is probably a significant bias towards insights in shifting diets in English speaking and western countries due to volume of research and access.

6. Recommendations for further action

This section has suggested that in the following areas further research is required:

- Stronger research engagement with the role of food production beyond the farm gate in helping to realise health-environment win-wins.
- A better understanding is required of the geographically specific nature of what a 'healthy and sustainable' diet looks like on a plate, and as a set of practices, and how this varies across place and culture.
- Research into the impact of integrating environmental factors into dietary guidelines is important. Existing healthy eating guidelines that integrate an environmental component (by Germany – published 2013, Brazil - 2014, Sweden - 2015 and Qatar - 2015) have been in place for the last 2-4 years. As the impacts of these guidelines 'play out' and begin to filter through the food system it will become increasingly viable to research and measure them.
- More research is needed to look at the socio-cultural elements of shifting diets towards lower meat, healthier and more sustainable diets.
- Further research should examine what macro-economic architectures that might support healthier and more sustainable food system outcomes look like.
- Cross health-environment interactions of policies aimed at each of these individually need to be better explored to ensure synergies can be maximised and negative trade-offs reduced or avoided.

More broadly, the following are recommended as possible courses of further action:

- Use recent policy developments around the Paris Climate Change Agreement and the SDGs, in addition to the pressing health challenges around food, to argue for an integrated health and environment approach to food systems (not just agriculture and not just the consumer).
- Promotion of health-environment win-wins in dietary guidelines beyond those countries currently doing this.
- Encouraging a move away from a dominant emphasis on action through individual choice in helping to realise health and environment outcomes around food and diet. A large range of interventions will be needed, at multiple levels, and examining what this suite of approaches looks like and how they achieve change will be important.
- Promote ambitious, staged, and robust school food and public institution food provision programmes, such as the Food For Life programme in the UK.
- Testing of promising approaches where evidence is scarce; using experimentation to build the evidence base.

References

1. Ericksen, P. J. Conceptualizing food systems for global environmental change research. *Glob. Environ. Chang.* **18,** 234–245 (2008).
2. Steffen, W. *et al.* Planetary boundaries: guiding human development on a changing planet. *Science (80-.).* **347,** 1259855 (2015).
3. Potts, S. G. *et al.* Global pollinator declines: trends, impacts and drivers. *Trends Ecol. Evol.* **25,** 345–353 (2010).
4. Vermeulen, S. J., Campbell, B. M. & Ingram, J. S. I. Climate Change and Food Systems. *Annu Rev Env. Resour* 195–222 (2012).
5. Intergovernmental Panel on Climate Change. *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment. Report of the Intergovernmental Panel on Climate Change.* **2014,** (Cambridge University Press, 2014).
6. De Schutter, L. & Lutter, S. *The true cost of consumption: the EU's land footprint.* (Institute

for Ecological Economics, Vienna University of Economics and Business and Friends of the Earth International, Belgium., 2016).
7. Millennium Ecosystem Assessment. *Ecosystems and human well-being: Synthesis*. (2005).
8. DeFries, R., Rudel, T., Uriarte, M. & Hansen, M. Deforestation driven by urban population growth and agricultural trade in the twenty-first century. *Nat. Geosci.* (2010). doi:DOI: 10.1038/NGEO756
9. Alexandratos, N. & Bruinsma, J. *World Agriculture towards 2030/2050. The 2012 Revision. ESA Working Paper No. 12-03.* (Agricultural Development Economics Division. FAO., 2012).
10. Ray, D. K., Mueller, N. D., West, P. C. & Foley, J. A. Yield Trends Are Insufficient to Double Global Crop Production by 2050. *PLoS One* **8,** e66428 (2013).
11. Delzeit, R., Zabel, F., Meyer, C. & Václavík, T. Addressing future trade-offs between biodiversity and cropland expansion to improve food security. *Reg. Environ. Chang.* 0–1 (2016).
12. Garnett, T. *Cooking up a Storm: Food, greenhouse gas emissions and our changing climate.* (2008).
13. Tilman, D. & Clark, M. Global diets link environmental sustainability and human health. *Nature* **515,** 518–522 (2014).
14. Smith, J. *et al.* Beyond milk, meat, and eggs: role of livestock in food and nutrition security. *Anim. Front.* **3,** 6–13 (2013).
15. Eisler, M. C. *et al.* Agriculture: Steps to sustainable livestock. *Nature* **507,** 32–34 (2014).
16. Health Council of the Netherlands. *Guidelines for a healthy diet: the ecological perspective.* (Health Council of the Netherlands, 2011).
17. Food and Agriculture Organization. *The state of world fisheries and aquaculture. Contributing to food security and nutrition for all, Food and Agriculture Organisation, Rome.* (FAO, 2016).
18. Westhoek, H. *et al. The Protein Puzzle. The consumption and production of meat, dairy and fish in the European Union.* (PBL Netherlands Environmental Assessment Agency, 2011).
19. Bostock, J. *et al.* Aquaculture: global status and trends. *Philos. Trans. R. Soc. Lond. B. Biol. Sci.* **365,** 2897–2912 (2010).
20. Mekonnen, M. M. & Hoekstra, A. Y. A global assessment of the water footprint of farm animal products. *Ecosystems* **15,** 401–415 (2012).
21. Food and Agriculture Organization. *Coping with water scarcity. An action framework for agriculture and food security.* (FAO, 2012).
22. Hess, T., Andersson, U., Mena, C. & Williams, A. The impact of healthier dietary scenarios on the global blue water scarcity footprint of food consumption in the UK. *Food Policy* **50,** 1–10 (2015).
23. Meier, T. & Christen, O. Environmental impacts of dietary recommendations and dietary styles: Germany as an example. *Environ. Sci. Technol.* **47,** 877–888 (2013).
24. Vanham, D., Mekonnen, M. M. & Hoekstra, A. Y. The water footprint of the EU for different diets. *Ecol. Indic.* 1–8 (2013).
25. Food and Agriculture Organisation. *Global food losses and food waste. Extent, causes and prevention.* (FAO, 2011).
26. Popkin, B. M., Adair, L. S. & Ng, S. W. Global nutrition transition and the pandemic of obesity in developing countries. *Nutr. Rev.* **70,** 3–21 (2012).
27. Hawkes, C. & Popkin, B. M. Can the sustainable development goals reduce the burden of nutrition-related non-communicable diseases without truly addressing major food system reforms? *BMC Med.* **13,** 143 (2015).
28. Bennetzen, E. H., Smith, P. & Porter, J. R. Decoupling of greenhouse gas emissions from global agricultural production: 1970-2050. *Glob. Chang. Biol.* **22,** 763–781 (2016).
29. Rogelj, J. *et al.* Paris Agreement climate proposals need a boost to keep warming well below 2 °C. *Nature* **534,** 631–639 (2016).
30. Nelson, G. C. *et al. Food security, farming, and climate change to 2050: challenges to 2050 and beyond*. (2010).
31. Myers, S. S. *et al.* Increasing CO2 threatens human nutrition. *Nature* **510,** 139–142 (2014).
32. Brown, M. E. *et al. Climate Change, Global Food Security, and the U.S. Food System.* (USDA, 2015).
33. Myers, S. S. *et al.* Climate Change and Global Food Systems: Potential Impacts on Food Security and Undernutrition. *Annu. Rev. Public Health* **38,** 259–277 (2017).
34. Challinor, A. J. *et al.* A meta-analysis of crop yield under climate change and adaptation. *Nat. Clim. Chang.* **4,** 287–291 (2014).
35. Cheung, W. W. *et al.* Structural uncertainty in projecting global fisheries catches under climate

change. *Ecol. Model. Vol* **325,** 57–66 (2016).
36. Nelson, G. C. *et al.* Climate change effects on agriculture: economic responses to biophysical shocks. *Proc. Natl. Acad. Sci. U. S. A.* **111,** 3274–3279 (2014).
37. Springmann, M. *et al.* Global and regional health effects of future food production under climate change: a modelling study. *Lancet* **387,** 1937–1946 (2016).
38. Hallström, E., Carlsson-Kanyama, A. & Börjesson, P. Environmental impact of dietary change: a systematic review. *J. Clean. Prod.* **91,** 1–11 (2015).
39. Tom, M. S., Fischbeck, P. S. & Hendricksen, C. T. Energy use, blue water footprint, and greenhouse gas emissions for current food consumption patterns and dietary recommendations in the US. *Environ. Syst. Decis.* **36,** 92–103 (2016).
40. Vieux, F., Darmon, N., Touazi, D. & Soler, L. G. Greenhouse gas emissions of self-selected individual diets in France: Changing the diet structure or consuming less? *Ecol. Econ.* **75,** 91–101 (2012).
41. Garnett, T., Mathewson, S., Angelides, P. & Borthwick, F. *Policies and actions to shift eating patterns: What works? A review of the evidence of the effectiveness of interventions aimed at shifting diets in more sustainable and healthy directions.* (2015).
42. Swedish National Food Agency. *Find your way to eat greener, not too much and be active*. (2015).
43. Health Council of the Netherlands. *Dutch dietary guidelines 2015*. (2015).
44. DEFRA. *Sustainable Consumption Report. Follow-up to the Green Food Project.* (Department for Environment Food and Rural Affairs, 2013).
45. Murphy, M. Dietary guidelines: scientific substantiation and public health impact. *Nutr. Bull.* **39,** 290–304 (2014).
46. Rooney, C. *et al. How much is '5-a-day'?: consumer knowledge of fruit and vegetable portion sizes*. *Proceedings of the Nutrition Society* **72,** (2013).
47. Bates, B., Lennox, A., Prentice, A., Bates, C. & Swan, G. *National Diet and Nutrition Survey Headline results from Years 1, 2 and 3 (combined) of the Rolling Programme (2008/2009 – 2010/11). A survey carried out on behalf of the Department of Health and the Food Standards Agency*. (2012).
48. Grunert, K. G. *et al.* Socio-demographic and attitudinal determinants of nutrition knowledge of food shoppers in six European countries. *Food Qual. Prefer.* **26,** 166–177 (2012).
49. National Geographic. *Greendex Summary of food results and analysis of behaviour change.* (2014).
50. Dibb, S. & Fitzpatrick, I. *Let's talk about meat: changing dietary behaviour for the 21st century*. (2014).
51. Macdiarmid, J. I., Douglas, F. & Campbell, J. Eating like there's no tomorrow: Public awareness of the environmental impact of food and reluctance to eat less meat as part of a sustainable diet. *Appetite* **96,** 487–493 (2016).