Food Production and Consumption in a 1.5°C World

Options for Germany

HotorCool

Authors:

Elli Latva-Hakuni (Hot or Cool Institute, Germany)
Magnus Bengtsson (Hot or Cool Institute, Germany)
Luca Coscieme (Hot or Cool Institute, Germany)

Contributing Authors:

Julian Deventer (followfood, Germany)
Gyde Wollesen (followfood, Germany)

Reviewers:

Ulrike Eberle (corsus - corporate sustainability GmbH, Germany), an earlier version of the paper
Dario Caro (Aarhus University, Denmark / Joint Research Centre of the European Commission, Spain), the analysis

Suggested citation

Latva-Hakuni, E., Bengtsson, M., Coscieme, L., Deventer, M.J. and Wollesen, G. (2023). Food Production and Consumption in a 1.5°C World - Options for Germany. Hot or Cool Institute, Berlin.

ISBN: 978-3-98664-009-5

This report was funded by followfood.

Contents

Key messages

- Balanced and sufficient nutrition is essential to our wellbeing. Yet, food and agriculture have a huge negative impact on the planetary systems that support life, contributing to around one-third of humanity's greenhouse gas emissions. In the future, food production will demand larger shares of the shrinking carbon budget to achieve the aspirational target of the Paris Agreement, while the share of less essential consumption areas must be reduced.
- To limit global warming to 1.5°C in a fair manner, per-capita food-related emissions must be below 775 $kgCO_{2-eq}$/year in 2030 and 360 $kgCO_{2-eq}$/year in 2050 for Germany.
- To meet the 1.5 target, the current carbon footprint of German diets (2300 $kgCO_{2-eq}$/person/year) must be reduced by over 66% by 2030 and 84% by 2050.
- Neither supply nor demand-side actions alone are enough to achieve the 1.5 target for food by 2030. More than half of the needed GHG reductions must be achieved through demand-side actions, especially changing diets. Changes in agricultural production practices and the following supply chains can at maximum contribute to 40% of the needed reduction.
- Required dietary changes compared to current levels must address the reduction of red meat consumption by 70%, other meat by 28%, dairy products by 26%, and beverages by 30%. Food overconsumption compared to nutritional needs must be tackled, and the consumption of vegetables, fruits, and plant-based proteins substantially increased.
- Shifting the German fish consumption to lesser climate impact fish species could reduce fish related GHG emissions by 42% and thus low climate impact fish products must be made more widely available.
- Plant-based diets require less land than meat-based diets thus offering a potential for reforestation and rewilding of agricultural areas, which can have major climate benefits. The agricultural area used for meeting German food demand, domestically and abroad, can be reduced by 17% if diets are aligned with the 1.5 target.
- Enabling a shift to low-carbon diets needs to address changes in the structures that shape consumer behaviour to make low-carbon food choices affordable, easily accessible, and in many cases the default option.

Summary

To limit global warming to 1.5°C above pre-industrial levels, the climate impact of food systems needs to be rapidly and substantially reduced. However, food production inevitably causes some greenhouse gas emissions which are hard or impossible to completely avoid in the following decades. In the future, food will need larger shares of the shrinking carbon budget, because proper nutrition is essential for human wellbeing. In 2050, food production is projected to make up half of the available carbon budget.

In this report, per-capita targets to limit global warming to 1.5°C were calculated for 2030 and 2050. German food consumption should stay within 775 $kgCO_{2-eq}$/person/year in 2030 and 360 $kgCO_{2-eq}$/person/year in 2050. Currently, the average German diet causes GHG emissions of 2300 $kgCO_{2-eq}$ per person each year, with meat, dairy and beverages taking the largest shares, 35%, 21%, and 15% respectively. The food-related carbon footprint needs to shrink by 66% to meet the 1.5 target in 2030 and by 84% in 2050.

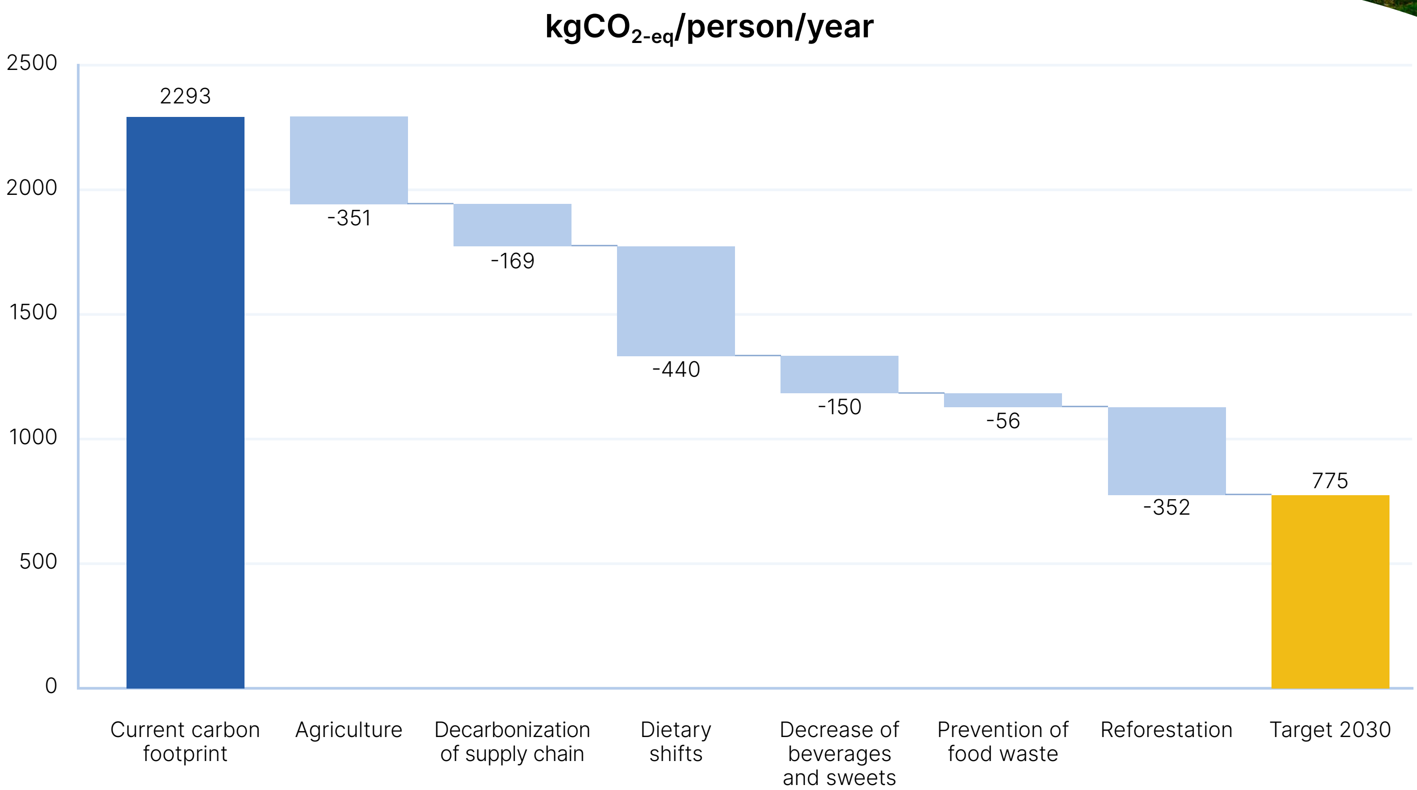
In this report, we estimate the climate impact of several supply and demand-side actions to mitigate the carbon footprint of German diets in 2030. Supply-side actions include improved methods in agriculture, such as rewetting fields located in drained peatlands or improving fertilizer management, as well as actions in the food supply chains. The full implementation of all the supply-side actions has the potential to reduce around 40% of the GHG mitigations needed to be in line with the 1.5 target. Thus, more than half of the necessary reductions need to be achieved through dietary changes and other demand-side actions.

Demand-side actions explored in the report include six diet models with more plant-based and healthy caloric intake. Other actions require switching red meat to low climate impact fish and dairy to plant-based milk alternatives, preventing household food waste and reducing beverages and sweets, which Germans currently overconsume. Plant-based diets also require less land area and thus offer possibilities to enhance carbon sequestration through the reforestation and rewilding of agricultural land.

Different dietary options, such as a diet following German nutritional recommendations or a vegetarian diet, can reduce the climate impact of German food consumption by 20-50%. However, even adopting the most low-carbon option, the vegan diet, is not sufficient to achieve the 1.5 target by itself.

A combination of supply and demand-side actions is needed to shrink the climate impact of German diets to be in line with the 1.5 target. The 1.5 pathway (Figure S1) indicates actions with achievable adoption rates that enable the German food consumption footprint to stay within the 1.5 target. Supply-side actions reduce the climate impact by 37%, while demand-side and reforestation affect 40% and 23% accordingly.

Dietary choices provide a huge potential to reduce the climate impact of German diets. Food choices are shaped by both unreflected habits and deliberate decisions which both can be targeted to enable the shift to low-carbon diets. Although changes in diets must be substantial, the transition needs to address gradual shifts to better food choices such as eating smaller portions of meat and linking low-carbon diets to other benefits such as health. Our food environment also has to change to enable low-carbon food choices as the default options. Dietary change is an area where large individual differences exist and where interventions thus need to be tailored to specific target groups.



▲ Figure S1. A possible pathway for German food consumption to achieve the 1.5 target ($kgCO_{2\text{-eq}}$/person/year). The pathway shows the needed actions and their potentials to mitigate the climate impact of German diets.

German food consumption and its climate impact

A fair climate transition that limits global warming to 1.5°C

The Intergovernmental Panel on Climate Change (IPCC) has stressed the need to limit global warming to 1.5°C above pre-industrial levels as our best chance to avoid the worst impacts of climate change (IPCC, 2018, 2023). Achieving the 1.5°C target would greatly reduce the risks of ecosystem collapse, extreme heatwaves, heavy precipitation events, agricultural and ecological damages from droughts, and sea-level rise, among others. The goal "to limit global warming to well below 2°C, preferably to 1.5°C" was adopted by 196 governments, as part of the legally binding Paris Agreement. Meeting the 1.5°C target requires rapid and substantial reductions in greenhouse gas emissions in all sectors, reaching net zero emissions globally by 2050.

At the global level, a fair climate transition requires high-income countries, which currently have much higher per-capita emissions than the global average, to shrink their carbon footprints faster than others. The German climate law, revised in 2021, recognises this responsibility partially by requiring the nation to achieve net-zero climate impacts already by 2045.

Current global and German food systems

Ensuring that our food consumption is sustainable, healthy, and equitable is one of the greatest challenges of our time. Current food consumption patterns are harming ecosystems and human health while environmental impacts, such as the worsening effects of climate change, are threatening agricultural production (Ivanovich et al., 2023; Springmann et al., 2018; Willett et al., 2019). Globally, food systems generate around one-quarter of all anthropogenic GHG emissions while strongly contributing to a range of other environmental impacts such as soil acidification, freshwater eutrophication, water scarcity, soil degradation, and biodiversity loss (Crippa et al., 2021; Poore & Nemecek, 2018; Springmann et al., 2018). In recent decades, the diets in high-income countries have changed towards more resource-consuming foods (Sun et al., 2022; Xu et al., 2021).

Food is one of the major contributors to the climate impact of households (Akenji et al., 2021; Beylot et al., 2019; Chitnis et al., 2014; Druckman & Jackson, 2016; Sala et al., 2019). In Germany, food contributes one-fifth of the climate impact of households (Miehe et al., 2016). This makes the agriculture and food system one of the priority areas for climate change mitigation.

This report assesses how German diets currently impact the global climate. It then explores how the carbon footprint of German diets could be reduced in line with the 1.5 target, considering both supply and demand side actions. These actions were combined to one scenario, the 1.5 pathway, that describes the needed actions to achieve the 1.5 target in 2030. The report examines GHG emissions and mitigation potentials through consumption-based accounting, which considers lifecycle emissions for domestically produced and imported agricultural inputs and food products.

Recent food trends in Germany

The interest towards plant-based diets and products has increased in recent years in Germany, but meat and dairy have still a prominent place in the Germans diet (BMEL, 2021). Large shares of the population consume daily meat (26% of the total population) and dairy products (64%) (BMEL, 2021). On average, Germans consume 56 kg of meat per person each year, of which 56% is pork, 24% poultry and 17% beef (BMEL, 2022). The German Nutrition Society recommends a maximum of 600 g of meat in a week (DGE, 2020), current consumption exceeds the upper limit by 45%.

In western countries, meat consumption has increased significantly in recent decades (Kanerva, 2013) and in Germany, the current amounts of meat consumed are 20% higher than 60 years ago (BMEL, 2022). Nevertheless, during the past decade in Germany, meat consumption has fallen by 12%, especially the consumption of pork (BMEL, 2022). Also, the share of organically produced foods in total household expenditure on food has almost doubled from 3% to 6% in 2009-2019 (BMEL, 2023).

German diets consist of domestically produced and imported foods. The country is a net importer of food, but it also exports abroad 30% of its domestic production (BMEL, 2020). For Germans' food consumption, large shares of vegetables, fruits, oil, and fish are imported (FAOStat, 2021).

The climate impact of the current German diet

On average, the German diet causes GHG emissions of 2300 $kgCO_{2-eq}$ per person each year (Figure 1) (for the calculation method and additional tables, see Methods brief). Animal-based products provide 27% of the calories and cause 60% of the carbon footprint whereas the impact of plant-based products is 40% of the carbon footprint and 73% of the caloric intake.

Meat has the highest impact, with a 35% share of the total food carbon footprint (CF). Pork contributes slightly more than beef (16% and 14% of the total CF). Beef has nearly three times higher climate impact per kilogram of meat, but Germans consume over three times more pork than beef.

Dairy is the second highest GHG emission source, with a 21% share. Cheese alone causes 7% of the total footprint. Germans consume significant amounts of coffee, soft drinks, and beer, 169, 118, and 92 litres/person/year respectively, and coffee or beer alone causes around 5% of the total CF. Vegetables, potatoes, fruits, and grains form another 21% of the CF. Currently, Germans eat small amounts of plant-based proteins, such as legumes and nuts, and they only have a 1% impact on the total CF.

Other studies of the carbon footprint of the German diet (Dräger de Teran & Suckow, 2021; Kolbe, 2020; Meier & Christen, 2012; Miehe et al., 2016; Paris et al., 2022; Treu et al., 2017) have reached similar results to the ones presented here, when differences in system boundaries of each study are considered. Common to all studies is that meat has the highest climate impact, followed by dairy products. In all studies available, animal-based products cause over half of the German diet's CF.

▲ Figure 1. The current carbon footprint of the average German diet.

Transforming food consumption for achieving the 1.5°C target

Reducing lifestyle carbon footprints - implications for different types of consumption

This study uses a 2030 target for food-related GHG emissions based on a method developed for the Hot or Cool Institute's 1.5°C lifestyle report series. To achieve the substantial GHG emission reductions needed for limiting global warming to 1.5°C, priorities need to be set between different categories of consumption, ensuring that essential needs can be met. Over time, emissions related to essential products, such as food, are therefore expected to make up an increasing share of the total carbon footprint. The method establishes targets for per-capita $CO_{2\text{-eq}}$ emissions for 2030 and 2050, then allocates emission shares for different lifestyle domains – such as food consumption and personal transport – based on how essential each domain is for human health and wellbeing.

The method also follows the principle of "contraction and convergence", which implies that high-emitting countries need to slash their emissions faster than the world average so that all countries converge to the same level of per-capita emissions at some point in the future. After the convergence year, all countries need to reduce their emissions so that the combined global emissions reach net-zero around 2050. The "1.5°C lifestyles report" sets the convergence year to 2030 (Akenji et al., 2021). Requiring high-emitting countries to make deeper cuts until 2030 leaves room for low-emitting countries to make essential infrastructure investments and some more time for the transition to zero-carbon energy systems.

The emission reduction pathway to be followed globally is based on scenarios included in the assessments by the IPCC. The 1.5°C lifestyles method uses scenarios with small temperature overshoot and only limited use of carbon removal technologies (CDR). The global emission levels that need to be reached by 2030 and 2050 are calculated based on the average of three such scenarios. Per-capita carbon footprints for the target years were calculated by dividing the global emissions by projected world population numbers. The resulting pathway for an average person's carbon footprint is shown in Figure 2 (Dark blue line). As can be seen, footprints would need to reach 3.4t by 2030 and 1.0t by 2050.

However, these footprint targets are based on societies' total emissions of greenhouse gases, including emissions from public spending and infrastructure investments – activities that are not closely related to the lifestyles of individuals and their consumption choices. To determine the share of total carbon footprints that are linked to individual lifestyles, the 1.5°C method relies on findings from Hertwich and Peters (2009). The resulting pathway for lifestyle carbon footprints is shown in the light blue line in Figure 2 where these footprints need to reach 2.5 $tCO_{2\text{-eq}}$ per person by 2030 and 0.7 $tCO_{2\text{-eq}}$ by 2050.

The share of food in lifestyle carbon footprints in 2030 and 2050

When the overall footprint is reduced, the share allocated to each domain will differ. Some domains, such as food, are essential for survival and health, thus making reductions difficult. Other consumption categories, such as parts of housing, consumer goods, and mobility, have a more dispensable nature. Hence, when footprints need to be reduced substantially, larger cuts will be required in such non-essential forms of consumption. This means that emissions from food systems will need to be reduced, but their share of the total carbon footprint will increase over time (Table 1). The detailed method of defining the 1.5 target and allocating the total lifestyle carbon budget to different consumption domains is described in the Methods brief.

Year	Predicted lifestyle carbon footprint share of domains (%)					
	Food	Housing	Mobility	Goods	Leisure	Services
2030	29%	31%	17%	10%	4%	8%
2050	50%	26%	9%	5%	3%	7%

▲ Table 1. Predicted lifestyle carbon footprint % shares of six consumption domains.

In the original method used in the 1.5°C lifestyle report, the share of predicted lifestyle carbon footprint for food refers to GHG emissions from cradle-to-store, while the food consumption phase, such as cooking and grocery transportation, is considered as part of other domains. The food consumption phase was estimated for Germany to be 50 $kgCO_{2\text{-eq}}$/person/year in 2030 and 10 $kgCO_{2\text{-eq}}$/person/year in 2050 (see Methods brief). The target for cradle-to-store is globally the same for everybody but the consumption phase is specific to Germany.

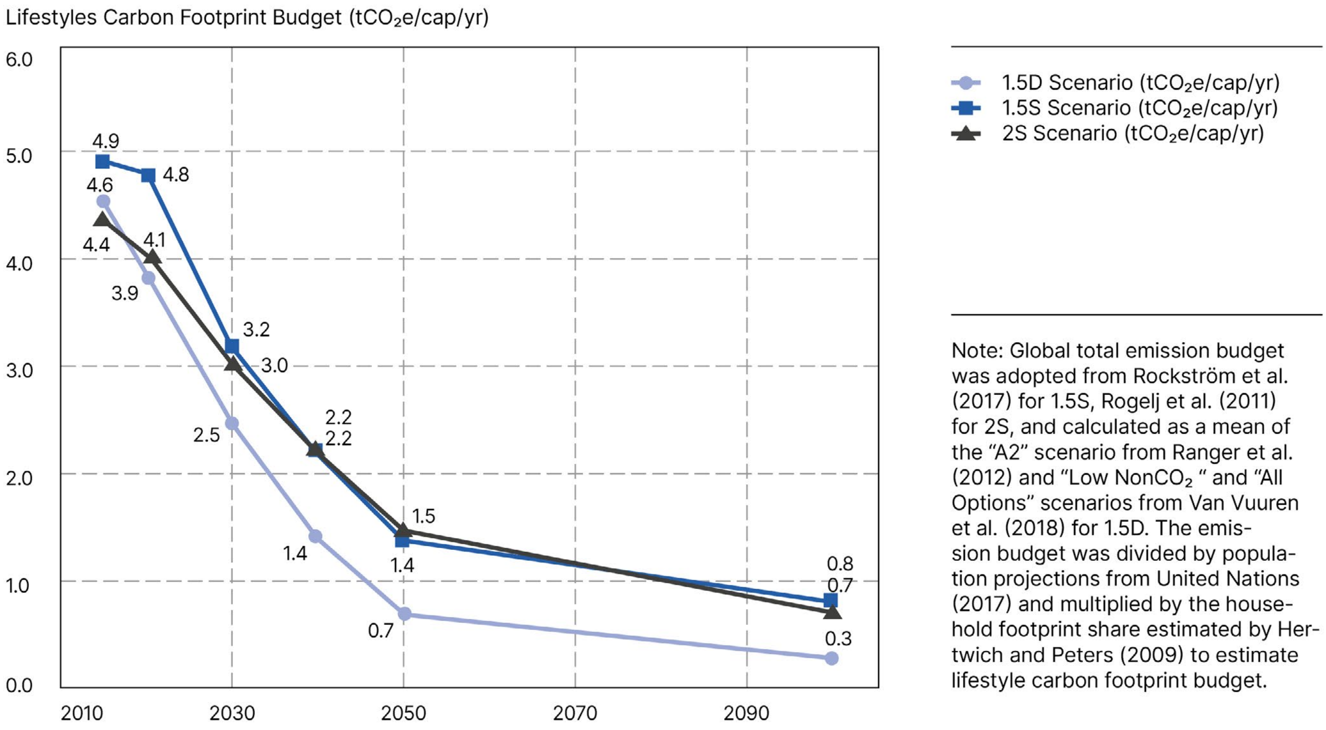
The 1.5 target for total food-related GHG emissions is 775 $kgCO_{2\text{-eq}}$/person/year in 2030 and 360 $kgCO_{2\text{-eq}}$/person/year in 2050. These targets are similar to Broekema et al. (2020) who estimated per capita food targets in line with the IPCC's 1.5°C report (IPCC, 2018), using the same equity approach and system boundary as in this report. Broekema et al. (2020) targets are 745 $kgCO_{2\text{-eq}}$/person/year in 2030 and 402 $kgCO_{2\text{-eq}}$/person/year in 2050.

The current carbon footprint of an average German diet (2300 $kgCO_{2\text{-eq}}$/person/year) exceeds the 1.5 target in 2030 (775 $kgCO_{2\text{-eq}}$/person/year) by over 1.5 tons $CO_{2\text{-eq}}$/person/year. The climate impact of German diets has to be reduced by 66% to meet the 1.5 target in 2030 and 84% in 2050.

[1] Reference "A2" scenario (Ranger et al., 2012), "Low Non-CO_2" scenario from (van Vuuren et al. 2018), and "All Options" scenario from (van Vuuren et al., 2018). More details on these scenarios are available in the 1.5°C lifestyles report (Akenji et al., 2021).

[2] Based on the median projection of the 2017 Revision of the World Population Prospects (United Nations, 2017).

Lifestyle carbon footprint budget from shortlisted mitigation pathways



▲ Figure 2. Pathways for carbon footprints until 2100 (Akenji et al., 2021).

Supply-side actions to mitigate the climate impact of the German diet

Supply-side actions to mitigate climate change considered in this analysis include changes in agricultural production as well as at later stages of the food system, such as food processing and retail. Also, food loss reductions at each stage are included. Mitigation potentials of supply-side actions assume realistic but ambitious values. The quantification of these potentials towards 2030 involves many uncertainties, and thus the analysis should be seen as indicative of their actual mitigation potential (Methods brief, Annex C).

Among all possible actions, we only investigated mitigation actions with quantitative data available in the context of German food consumption. Accordingly, some mitigation actions could not be considered (see Methods brief).

Mitigation actions in agriculture

Changes in agricultural practices can both reduce GHG emissions and enhance the carbon sequestration capacity of agricultural land. The mitigation potentials of agricultural actions differ depending on the geographical area and were thus calculated separately for German domestic production and imported foods and subsequently combined into one estimate.

For Germany's domestic food production, the most effective mitigation action is rewetting of drained peatlands, which are currently used as agricultural fields. It is estimated that drained peatlands today are covered by 1 Mha of grassland and 0.3 Mha of croplands, and together they make up 7% of the total agricultural area (Don et al., 2018; Grethe et al., 2021). Drainage increases the organic carbon decomposition and thus shifts the peatlands from carbon sinks into significant sources of CO_2. Rewetted peatlands cannot be used for common agriculture, but paludiculture can be practised. Paludiculture is the agricultural use of soils in wet conditions. In Europe, it is mainly used for growing biomass for fodder, biofuel production, and raw materials for construction but also for grazing with cattle adapted to wet conditions (Ziegler et al., 2021). In this study, we consider a scenario in which 25% of the drained peatlands are rewetted, used for paludiculture, or taken out of production (e.g., as natural conversation areas), while 50% are turned into extensive grasslands (Methods brief, table 4).

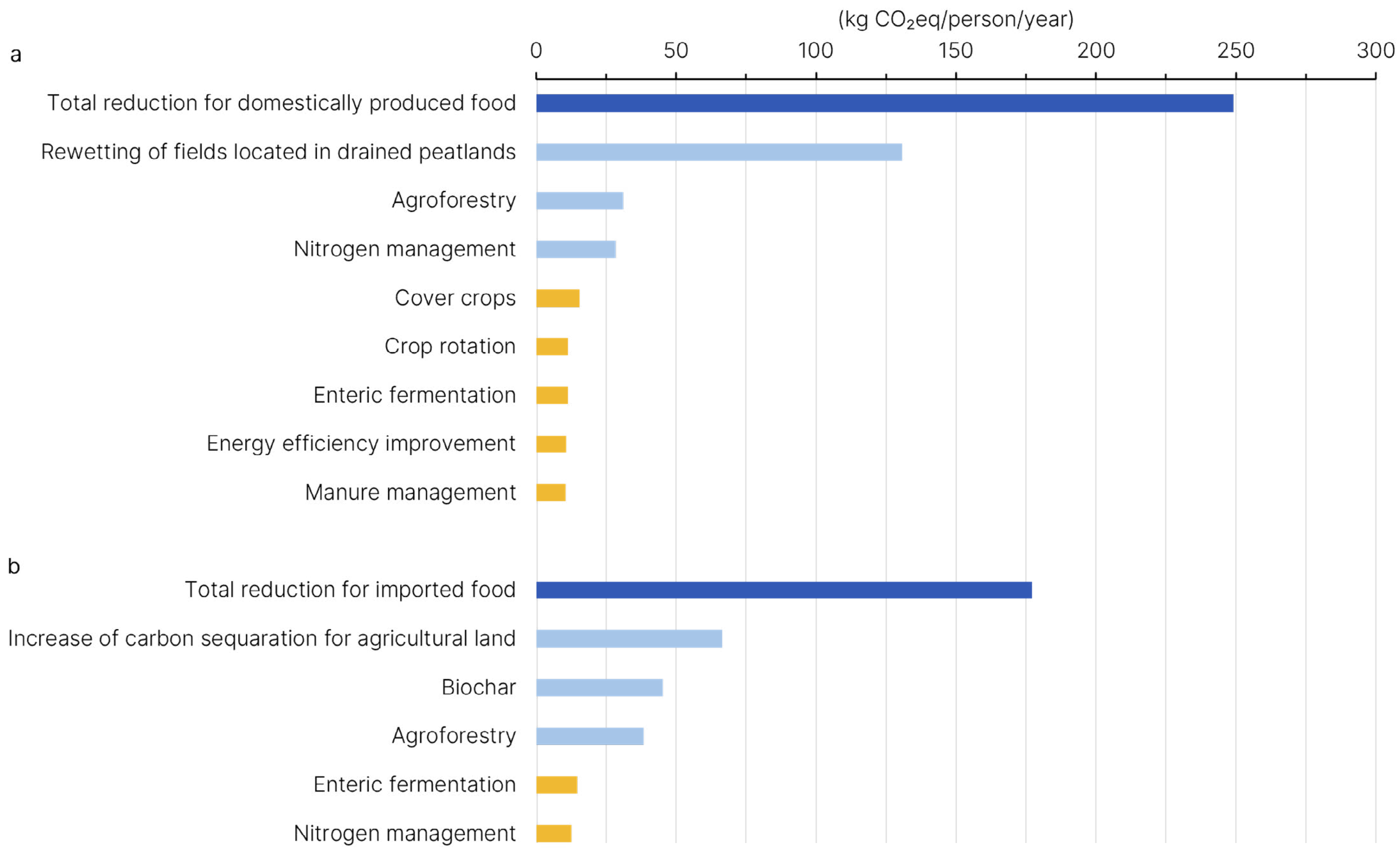
Other selected agricultural management actions, which reduce GHG emissions, are nitrogen fertilizer management, enteric fermentation, manure management, and energy efficiency. Nitrogen fertilizers affect the release of N_2O (a greenhouse gas with a climate forcing that is 298 times that of CO_2) from soils to the atmosphere. Also, the production of mineral nitrogen fertilizers is highly energy intensive, often produced using fossil gas as fuel. These GHG emissions can be reduced by optimising and reducing the total fertilizer application (Methods brief, table 5). Enteric fermentation causes CH_4 emissions from the digestion system of ruminants (a greenhouse gas with a climate forcing that is 37 times that of CO_2). These GHG emissions can be mitigated by food additives and drugs, which inhibit CH_4 production, and actions to improve animal production efficiency (Knapp et al., 2014) (Methods brief, table 6). Emissions of CH_4 and N_2O from livestock manure management can be prevented through improved collection, storage and spreading techniques and manure can also be used for biogas production (Roe et al., 2021) (Methods brief, table 6). The main areas to reduce energy consumption in German agriculture are greenhouses, poultry houses, pigsties, and facilities for milk production (BMEL, 2016) (Methods brief, table 7).

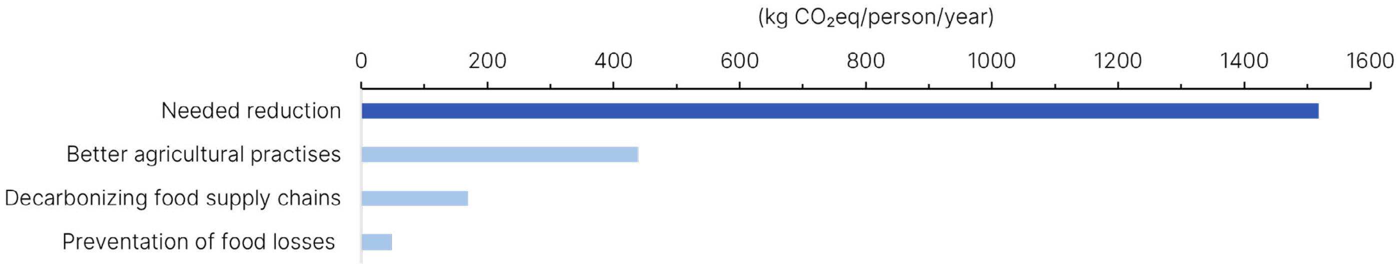
Agriculture also has a big potential to sequestrate carbon from the atmosphere, storing it in biomass or soil. In this study, three options for sequestration were explored: cover crops, crop rotation and agroforestry (Methods brief, table 8). Cover crops are the cultivation of temporary fast-growing plants to cover the soil between arable crops, typically over winter (Poeplau & Don, 2015). Crop rotation, such as the cultivation of legumes, crops with dense and deep root systems and perennial crops, may also increase soil organic carbon (SOC, Wiesmeier et al., 2020). Agroforestry is an integration of trees and shrubs into crop and animal farming systems, and it has the potential to add carbon to aboveground woody biomass as well as into the soils (Golicz et al., 2021). In Germany, hedgerows between fields are a traditional way of integrating trees and shrubs into agricultural lands (Drexler et al., 2021).
The mitigation potentials used for imported foods are based on global meta-analyses (Griscom et al., 2017; Searchinger et al., 2018; Roe et al., 2019; Roe et al., 2021). The actions included in this analysis are nitrogen fertilizer management, biochar, agroforestry, improved enteric fermentation and actions to enhance carbon sequestration in agricultural lands (Methods brief, table 9).

The combined effect of agricultural actions

For the total reduction potential of agricultural actions, 26% comes from carbon sequestration actions while the remaining 76% is from actions which reduce GHG emissions. The most effective action is rewetting agricultural peatlands, as other studies have also concluded (Jacobs et al., 2018; Prognos, Öko-Institut & Wuppertal Institute, 2020).

▼ Figure 3. GHG emission reduction potentials (kg$CO_{2\text{-eq}}$/person/year) of agriculture, clustered by domestically produced food (a) and imports (b). Dark bars on top indicate the total reduction potential of domestically produced food and imports. Values consider the different shares of domestically produced and imported foods in the current diet.





▲ Figure 4. GHG emission reduction potentials of production side action (kg$CO_{2\text{-eq}}$/person/year) in 2030. Top-bar describes the needed reduction to reach the 1.5 target in 2030.

Based on our results, in 2030, rewetting makes up 52% of the total mitigation potential of all agricultural management actions for domestically produced food (Figure 3a). For German food consumption, excluding exports and including imports, partly rewetting agricultural peatlands in Germany is still 29% of the total mitigation potential of agricultural management actions of German diets. Other impactful actions are nitrogen fertilizer management and agroforestry. Their effect, including both domestically produced and imported foods, is 9% and 16% of the agriculture's mitigation potential, respectively.

Other supply-side actions

In addition to improved agricultural practices, there are opportunities to reduce GHG emissions from food supply chains, in industrial processes, food packing, retail, transport, and waste management. In 2030, supply chains are assumed to have partly shifted away from fossil fuels by reducing energy and fuel consumption, shifting to renewable energy sources, and reducing the GHG emissions released from cooling appliances and waste management processes (Crippa et al., 2021; Prognos, Öko-Institut & Wuppertal Institute, 2020) (see Methods brief). Reducing food loss at pre-consumer stages is also included in the analysis as a supply-side action.

Partly decarbonizing the supply chains in 2030 reduces the total climate impact of the German diet by 7% and reduced food losses by 2%. Comparing all the supply-side actions presented above, the actions from agriculture make up 67%, decarbonizing the food supply chains contributes 26% and preventing food losses adds another 7% of the total mitigation potential of supply-side actions. This implies that full implementation of all the supply-side actions considered in this study has the potential to reduce the carbon footprint of German food consumption by 29%, corresponding to 43% of the reduction needed to stay within the 1.5°C limit (Figure 4). In other words, more than half of the necessary reductions need to be achieved through dietary changes and other demand-side actions.

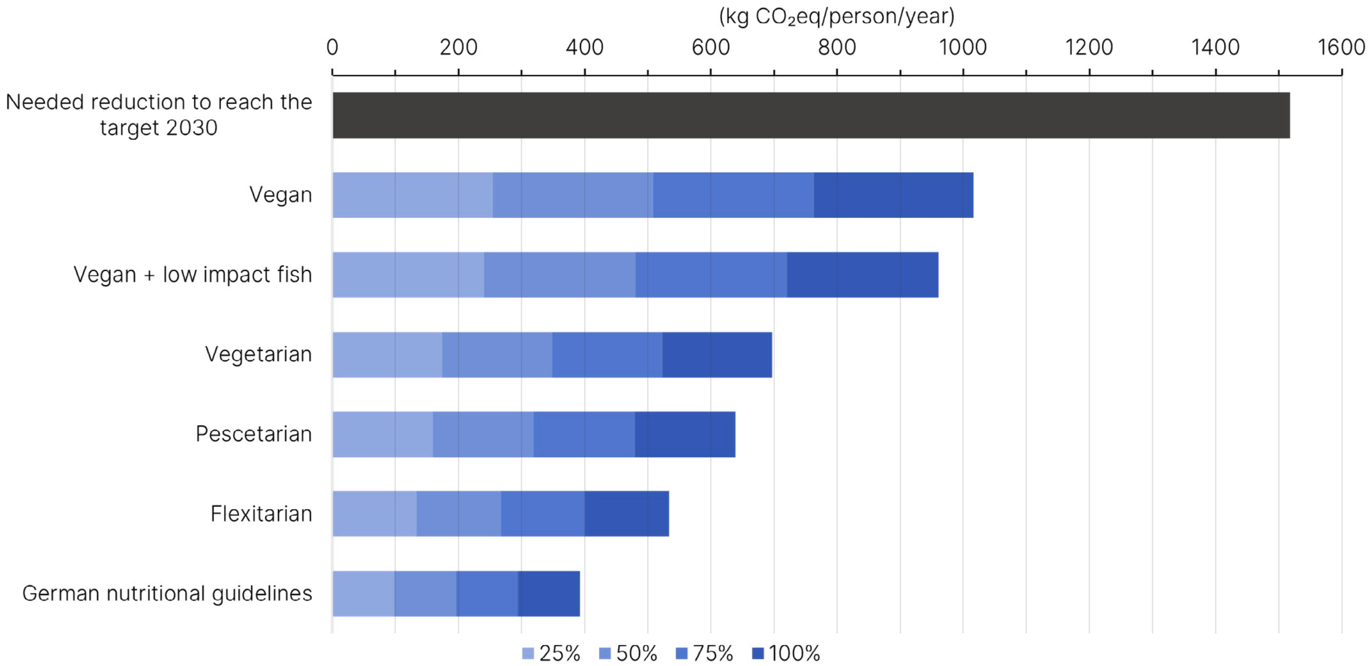
Demand-side actions to mitigate the climate impact of the German diet

For demand-side actions, we propose six alternative diets to reduce the climate impact of food consumption in Germany. Earlier studies have identified dietary shifts as one of the most effective ways to reduce food-related GHG emissions (Bajželj et al., 2014; Hallström et al., 2015; Poore & Nemecek, 2018; Springmann et al., 2018). In addition to the dietary options, four other consumption actions were explored (calculation method, see Methods brief). Two of these actions consider shifts from individual food categories with high climate impact to others with lower impact: shifting red meat to low-impact fish and dairy products to plant-based alternatives. These actions are not additional to dietary options as diets already include changes in food categories. The other two options assessed, reduce the amount of food consumed: reducing beverage consumption and preventing household food waste.

Mitigation potentials of the actions are shown with adoption rates of 25, 50, 75 and 100%. Rates describe the share of the population or the degree of individual adoption of the diet. For example, a 50% rate for a vegetarian diet indicates that either 50% of the population switches to completely this diet or each individual switches half of their diet to the vegetarian diet.

Dietary options

Six alternative diet models were formulated to mitigate the food's climate impact while ensuring healthy and nutritionally adequate nutrition. Diets include a diet following the German nutritional guidelines (DGE, 2022), a vegan diet specific to Germany (Weder et al., 2018) and a flexitarian, vegetarian and pescetarian diet from EAT-Lancet report (Willet et al., 2019). One more dietary option was created to explore the impact of a plant-based diet which includes low-climate-impact fish and seafood ("vegan + low-impact fish"). The dietary options consider reducing caloric intake to healthy levels and beverage consumption was assumed to stay the same as in the current German diet (the composition of diets, see Methods brief, Annex B). The reduction of beverages was studied in a separate action.

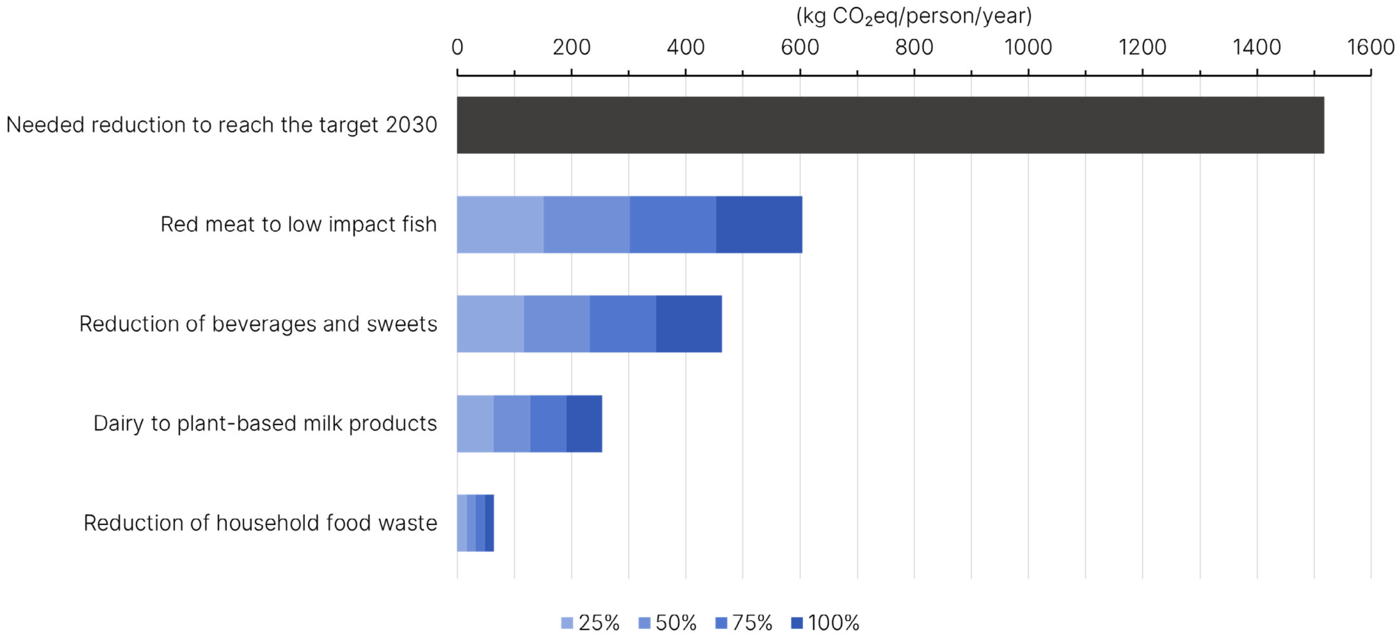


▲ Figure 5. GHG emission mitigation potentials for different dietary options (kgCO2-eq/person/year). The top bar represents the reduction needed to achieve the 1.5 target in 2030. Adoption rates shown as different shades of blue represent the share of the population or the degree of individual adoption of the diet.

Our results show that diet changes can reduce the carbon footprint of food in Germany by 20-50%. The lowest reduction (20%) is achieved by adopting the German nutritional guidelines diet. The highest reduction (50%) is achieved by adopting the vegan diet. Results are similar to other studies, in which a flexitarian diet reduces GHG emissions by around one-third of the average German diet and by half for a vegan diet (Dräger de Teran & Suckow, 2021; Paris et al., 2022).
Comparing dietary changes to supply-side actions, adopting a vegan diet reduces the total food footprint by 18% more than implementing all the supply-side actions considered in this report. Shifting to a pescetarian or vegetarian diet shows similar mitigation impacts as the combined impact of all supply-side actions.
However, even adopting a vegan diet is not sufficient alone to reach the 1.5°C target (Figure 5). With a vegan diet, 67% of the needed reduction can be achieved, while a flexitarian diet allows to achieve 35% of it (Figure 5). This underlines that while dietary changes are crucial, changes in agricultural practices and supply chains are also needed for limiting global warming under 1.5°C.

Co-benefits of climate change mitigation and human health

Based on recent findings (GBD, 2019), adopting a less GHG-emitting diet yields further health benefits besides limiting climate change impacts. Currently, German eating habits are linked to several diet-related risk factors (GBD, 2019). Shifting towards plant-based eating habits supports health, reducing the risk of developing coronary heart diseases, high blood pressure, diabetes, and increasing longevity (Paris et al., 2022; Tilman & Clark, 2014; Springmann et al., 2016; van Dooren et al., 2014). Dietary shifts thus constitute an effective solution for multiple environmental and health impacts connected to food consumption, in turn leading to important savings in public and private health costs and increased societal wellbeing (Jardim et al., 2019; Laurent et al., 2021).



▲ Figure 6. Other demand-side actions and their mitigation potentials (kg$CO_{2\text{-eq}}$/person/year). The top bar represents the GHG emission reduction needed to achieve the 1.5 target in 2030. Adoption rates shown as different shades of blue represent the share of the population or the degree of individual implementation of the action. For example, a 50% rate in reduction of household waste indicates that either 50% of the population reduced all edible food waste, or each individual reduced half of their food waste.

Other demand-side actions

Among the other demand-side actions, replacing red meat (beef, pork, and mutton) to low-impact fish has a big potential to reduce the climate impact of German diets (Figure 6). Replacing dairy products with plant-based alternatives, such as oat milk or yoghurt, reduces the food carbon footprint by 11%, contributing to 17% of the total emission reduction needed to achieve the 1.5 target (Figure 6).

The reduction of beverages and sweets to zero would reduce the climate impact of the German diet by 20% and contribute to 31% of the needed reduction to achieve the 1.5 target (Figure 6). A reduction in household food waste will reduce the carbon footprint of German diets by 3%, contributing to 4% of the needed 1.5 target reduction (Figure 6). In our analysis, this action considers only the edible food parts of the household food waste (32 kg/person/year) and excludes inedible parts such as vegetable peels and coffee grains (BMEL, 2022). Currently, 65% of the total food waste along the supply chain happens at household level (BMEL, 2022) and thus this demand-side action yields a larger impact than supply-side action. If all avoidable food waste is prevented, the CF of German diets are reduced by 6%. The climate mitigation impact of food waste reduction is smaller compared to the mitigation potentials through dietary and supply-side actions, a result that is noticed also globally (Ivanovich et al., 2023).

The full population-wide 100% adoption of the actions may not be plausible, but also smaller adoption rates provide notable mitigation potentials.

Climate impact of fish and seafood products

The carbon footprint of fish varies greatly due to the wide range of production and fishing techniques. On the low end of carbon footprints are farmed bivalves and small pelagic fish such as mackerel, herring, and sardines. These low-impact blue foods, with a carbon footprint of 1 to a few kg $CO_{2\text{-eq}}$/kg, may cause lower GHG emissions than chicken or some plant-based proteins (Gephart et al., 2021; Ritchie & Roser, 2021). In turn, wild flatfish and crustaceans such as flounder and lobster are at the upper end of blue food carbon footprints, generating about 20 kg$CO_{2\text{-eq}}$/kg. While mitigating the climate impact of blue food, it is important, however, to evaluate the overall environmental performance, as lower carbon footprint products may sometimes generate higher environmental impacts beyond climate change (Parker et al., 2018).

While the amount of fuel used for fishing drives the GHG emissions of fisheries (Parker et al., 2018; Ziegler et al., 2016), feed production is the main contributor to aquaculture. Fuel use is closely linked to the targeted species and the fishing method used for capture and can vary by over ten times per kg of captured fish (Parker et al., 2018). The highest fuel consumptions were reported for the bottom trawling/traps of flatfish or crustaceans, whereas fisheries targeting small pelagic fish deploying surrounding nets or pelagic trawling show the lowest fuel uses per yield (Parker et al. 2018).

For aquaculture, the amount and ingredients of feed strongly affect the carbon footprint. However, not all aquaculture needs feed. No-input or restorative systems, such as coastal farms growing seaweed and molluscs or brackish/freshwater systems growing shrimp and carp, may provide blue foods with small carbon footprints (Gephart et al., 2021; Ritchie & Roser, 2021) and there is evidence they also provide a range of ecosystem services (Barrett et al., 2022).

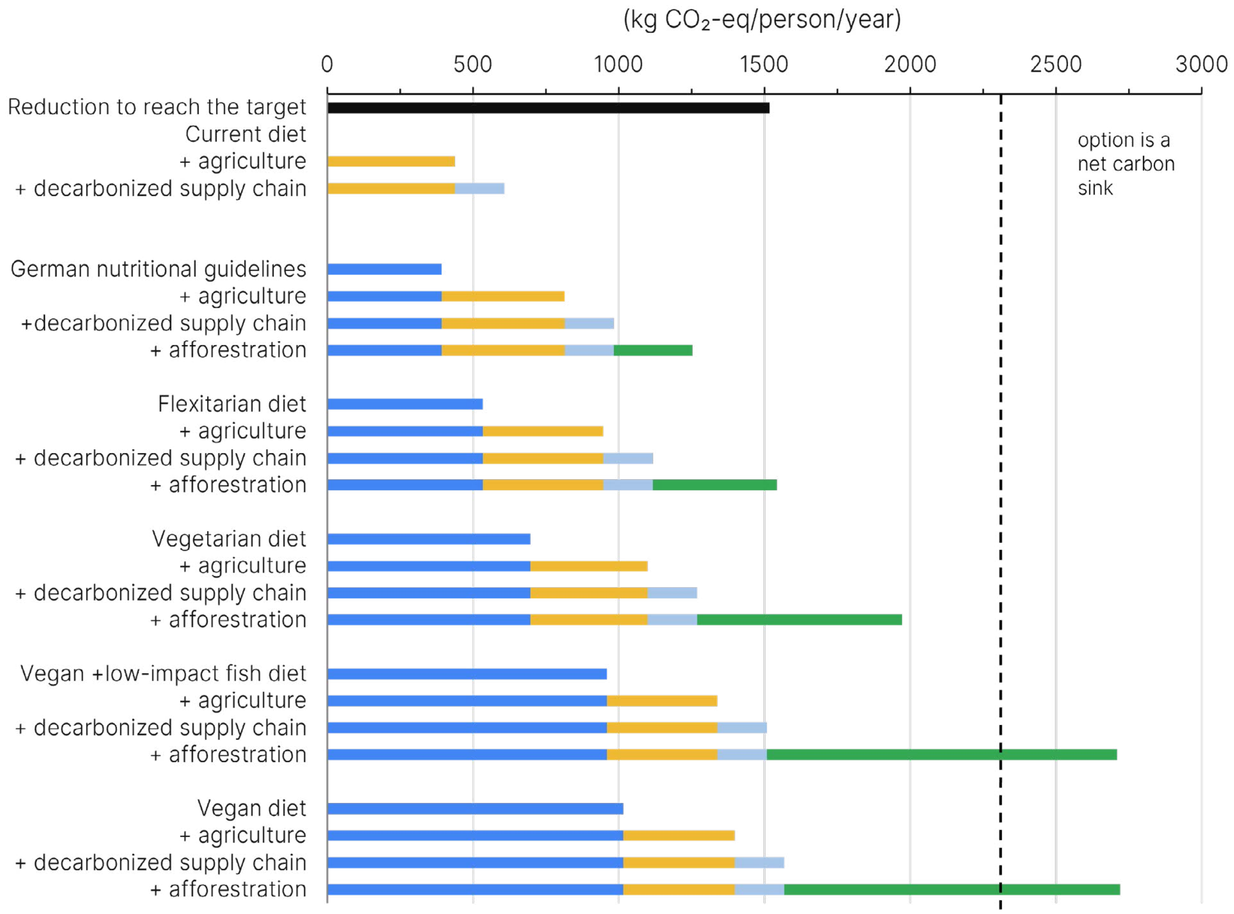
Food consumption pathways to a 1.5°C future

Climate mitigation potential of dietary choices and supply-side actions

Through a combination of dietary changes and supply-side actions, the current carbon footprint of food consumption in Germany can be substantially reduced (Figure 7). This section presents how combinations of such actions could be aligned with the 1.5°C target. In addition to diet changes and supply-side actions, the section includes the reforestation/afforestation of current agricultural fields as one additional action to reduce GHG emissions. Dietary changes, in fact, can allow for a reduction in the extent of agricultural land, which can be reforested (Chan et al., 2022; Dräger de Teran & Suckow, 2021; Hayek et al., 2021).

Freed land areas can be used for native vegetation regrowth, offering the potential for increasing carbon sequestration. In this analysis, it was assumed that 50% of freed cropland area is reforested and the other half is used for non-food crop cultivation or is located on land not suitable for forestation (see Methods brief). Grassland areas can also be freed as a result of reducing meat production and consumption. For these, it was assumed that grasslands that have earlier been forests are reforested while native grasslands stay unchanged (Methods brief, table 10). The climate mitigation impact of reforestation as well as the direct link between dietary changes and reforestation hide a high level of variability which is required to make several assumptions (Methods brief). The overall impact of this action should thus be considered as a first indicative estimate to be refined in further studies.

The results of this report show that no single diet option by itself is enough to achieve the aspirational target of the Paris Agreement. Instead, a combination of dietary shifts, supply-side actions, and reforestation is needed. As an example, the full adoption of a flexitarian diet, the implementation of all supply-side actions, and reforestation would allow to achieve the 1.5 target (Figure 7). Vegan and vegan + low-impact fish diets combined with all supply-side actions and reforestation would make the food system carbon negative until the vegetation of reforested areas matures (Figure 7). In this case, areas that are currently used for agriculture but are reforested would sequester and store more carbon than the amount of greenhouse gases generated by food production.



▲ Figure 7. The reduction potentials of different dietary options combined with supply-side actions and reforestation (kgCO2-eq/person/year). The dark blue bars represent the reduction potential of each diet; the yellow bars show the reduction potential when implementing actions in agricultural production; the light blue bars show reduction potential through decarbonization of the supply chain; the green bars show the reduction potential for reforestation; the top black bar shows the GHG reduction needed to keep food consumption-related emissions in line with the 1.5°C target in 203

Pathways to align food consumption in Germany with the 1.5°C target

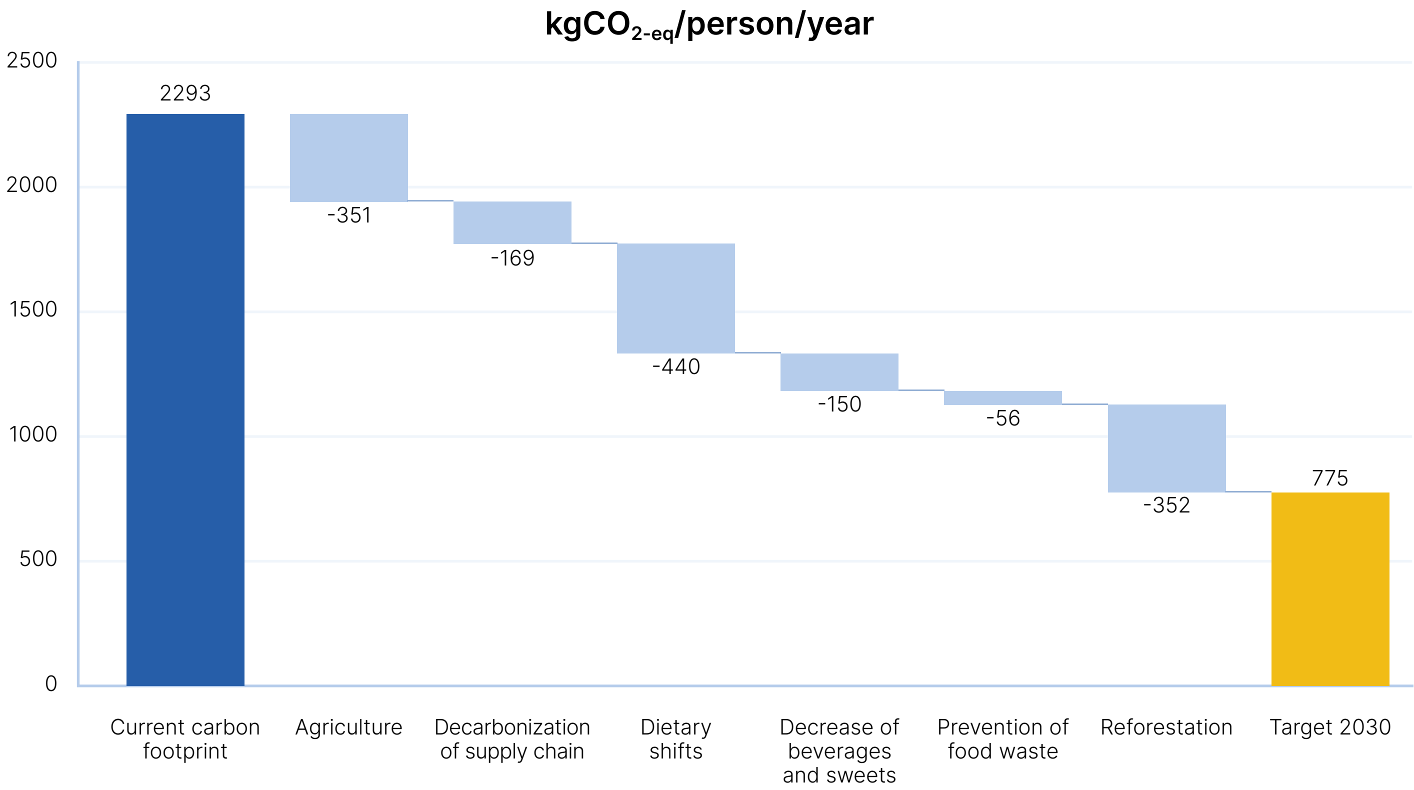
Neither supply- nor demand-side actions alone are enough to achieve the 1.5 target in 2030, indicating the need for an integrated approach. We combine actions from both sides into one scenario, the 1.5 pathway, which includes the needed actions to reduce the climate impact of German diets to be in line with 1.5 target.

The magnitude of the impacts of different actions depends on their adoption rates and the 1.5 target can be met with variable combinations of adoption rates. The 1.5 pathway considers the most achievable adoption rates which still enable German diets to stay within the 1.5 limit (reasons and references of the chosen rates, Methods brief, table 11). For the supply-side, actions in agriculture were assumed to be implemented by 80% of their maximum potential and decarbonization of the food supply chain was expected to achieve the German national climate targets for the energy and transportation sectors. For demand-side actions, the consumption of beverages and sweets is reduced by 30% from current levels and 80% of the population is following a flexitarian diet including a healthy caloric intake. Reforestation potential is estimated based on the dietary change which enables a 17% reduction in agricultural areas.

In the 1.5 pathway, supply-side actions reduce the climate impact by 37%, while demand-side and reforestation affect 40% and 23% accordingly. Other studies have also identified dietary choices and reforestation as large contributors to the climate mitigation of food systems, globally (Crippa et al., 2021; Hayek et al., 2021; Willett et al., 2019) and in Germany (Rasche et al., 2023).

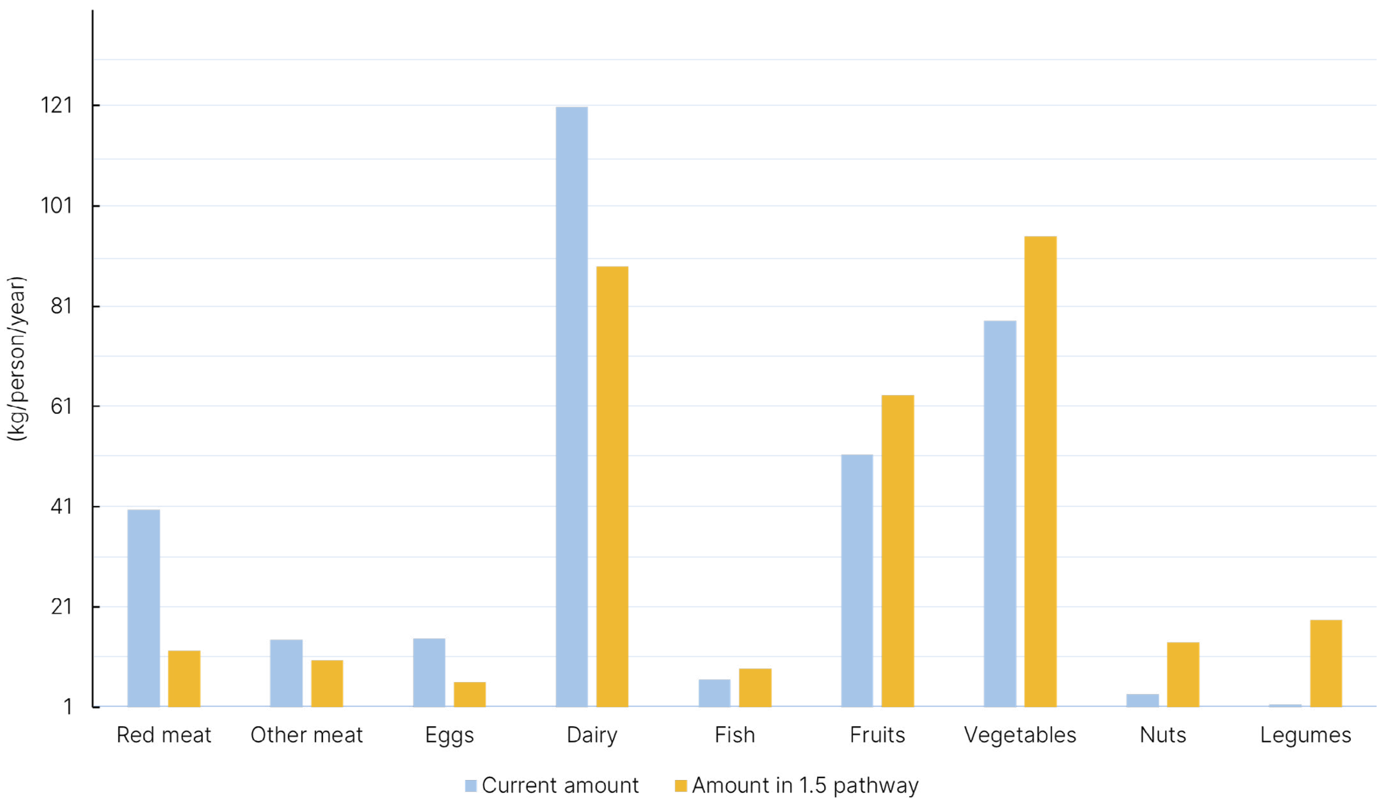
The 1.5 pathway will lead to substantial changes in food consumption in Germany, reducing animal-based products while increasing vegetables, fruits, and plant proteins (Figure 9, Table 2). The only exception is fish, which can be increased over 30% (Table 2). The biggest reduction must happen in red meat consumption which has to decrease by 70%. Although meat consumption has fallen by 12% in the past decade in Germany, which is relatively one of the biggest among European countries (FAOStat, 2021), in the future the reduction rate must be faster. At current reduction rates, it would take over 40 years to reach meat consumption levels in line with the 1.5 pathway in 2030. However, there is also large variability of meat production practices and their environmental impacts, for example optimized grazing systems may have a big potential to increase soils organic carbon content temporarily at a local scale (Rowntree et al., 2020; Stanley et al., 2018).

The amount of legumes increases over ten-fold in the 1.5 pathway compared to the current average German diet (Table 2). Currently, Germans eat small amounts of legumes (4,5 g/person/day, BMEL 2022) and to make them more culturally acceptable, legumes can be processed into different products such as meat analogues. In the future, novel protein sources, such as algae, insects, or proteins produced by fungi or microbes, can also provide alternatives to animal-based proteins (Mazac et al., 2022; Scherer et al., 2023).



▲ Figure 8. A possible pathway for German food consumption to achieve the 1.5 target (kg$CO_{2\text{-}eq}$/person/year).

▼ Figure 9. The amounts (kg/person/year) of different food groups in the current average German diet and in the 1.5 pathway.



Changes in food groups	% share from current diet habits to the 1.5 pathway
Red meat	-70 %
Other meat	-28 %
Eggs	-38 %
Beverages	-30 %
Dairy	-26 %
Fruits	23 %
Vegetables	22 %
Fish	34 %
Nuts	287 %
Legumes	1028 %

Table 2. Changes in food groups according to the pathway to achieve the 1.5 target in 2030. %-shares describe changes in food amounts from current diets to the 1.5 pathway.

Notes on the analysis

This report considers conservative values for estimating the mitigation potential of technological and land-based solutions (for an overview of the range in the current literature, see Methods brief, Annex C). Mitigation potentials are calculated for 2030, which is under a decade from now, and it is unlikely that many new innovations would reach a large-scale implementation stage in such a short time. In the future, technological and land-based solutions could show a bigger potential to reduce GHG emissions, but analysis of low-carbon pathways should carefully consider their actual implementation rate and assess possible rebound effects (Akenji, 2022).

The analysis in this report only considers the climate impacts of food, without assessing any other environmental impact. Although a shift towards more plant-based diets presents synergies in terms of mitigation of other environmental impacts (Poore & Nemecek, 2018), trade-offs also exist. For example, the diet shift proposed in this report to achieve the 1.5 target in Germany implies a two-fold increase in nut consumption, with important impacts in terms of water use in contexts of water scarcity (Poore & Nemecek, 2018). As uncertainties about the environmental impacts of different food products are better reconciled in the future, dietary guidance would need to be re-evaluated.

Enabling a shift to low-carbon diets – research-based insights

The findings of this study underline the need to transform all parts of the agriculture and food system. Only when low-carbon agriculture, food processing, and distribution are combined with significant changes in diets can a global warming of more than 1.5°C be avoided. This requires that governments, businesses, and citizens all play their part. Governments must set the rules of the game by ensuring that economic incentives are aligned with a low-carbon transition and that the knowledge and skills needed for climate-friendly choices are in place. They must also make sure that the transition is fair, including protecting those whose livelihoods are negatively affected.

While the need for changes on the production side is widely recognised, as indicated by the growing interest in regenerative and climate-smart agriculture, the need for dietary changes is generally less accepted. This can be due to a lack of knowledge either on what changes in diets are needed or on how such changes can be brought about. This analysis presented in this report shows what changes in consumption are needed – primarily a shift from diets with high shares of meat and dairy products to plant-based nutrition, possibly combined with some low-impact protein sources. This section provides a summary of existing research on how to bring about such dietary changes.

Our dietary choices are shaped by both conscious and unconscious habits and deliberate decisions . This means that some food-related decisions are part of everyday routines where consumers spend only a minimum amount of time considering what to eat – situations characterised by “fast thinking.” In these situations, only a few factors like availability, preparation time, price, and previous experience (habits) tend to dominate while factors such as health and environmental impacts usually receive less consideration. Other decisions are the result of “slow thinking” where a wider range of factors is considered. Research on dietary changes recognises the significance of both types of decision-making processes and finds that influencing strategies often need to target both to be effective.

Providing consumers with information is both necessary and insufficient. Shifting attitudes requires providing consumers knowledge on why certain lifestyle changes are desirable and how those changes can be beneficial for both society and the individual. However, research shows that just providing such information often has little impact on behaviour or is effective only on a small share of the population (Bergquist et al., 2023). This is why there is usually a need also for changes in infrastructure – the physical availability and convenience of low-carbon options – and enablers, such as price incentives and easy-to-understand information systems that help consumers identify better options.

Despite the limitations of consumer education as a main strategy, raising public awareness of climate change remains essential. If people are convinced that the climate is changing and that the impacts are very serious but also that the worst-case scenarios can still be avoided through decisive action, they are more likely to follow advice on climate-friendly food consumption. A good understanding of the seriousness of climate issues is also important for people’s willingness to accept political decisions aimed to make lifestyles less damaging to the climate.

Research on how to change diets in a climate-friendly direction is diverse and findings are sometimes contradictory. However, the following seven recommendations have strong support in the literature. Each recommendation is followed by a few examples of related research publications.

- Recognise that there are large individual differences - interventions need to be tailored to specific target groups (Lacroix et al., 2022)
- Begin by targeting groups that are more likely to change, such as women, youth, and people with other pro-environmental behaviours (Pohjolainen et al., 2015; Sparkman & Walton, 2017; Lea et al., 2006; Krizanova et al., 2021)
- Emphasise other benefits than climate protection, especially health and animal welfare (Eurobarometer, 2022; Lea et al., 2006; Miki et al., 2020; Van Loo et al., 2017; Ohlau et al., 2022; Mathur et al., 2021; Harguess et al., 2020; Reipurth et al., 2019; Michel et al., 2021; Kwasny et al., 2022)
- Don’t aim for perfection but facilitate gradual changes through multiple diet pathways (de Boer et al., 2014)
- Use simple campaign messages and symbols (Edenbrandt & Lagerkvist, 2021)
- Make better options the easy and natural choice through “nudging” (Gravert & Kurz, 2021; Harguess et al., 2020; Abrahamse, 2020)
- Consider how to maintain climate-friendly dietary changes over the long term (Taufik et al., 2019)

Conclusions

To achieve the target of the Paris Agreement and limit global warming to 1.5°C, per capita targets are determined by distributing the remaining carbon budget on an equitable basis across the global population (Akenji et al., 2021). This report follows this equity-based approach to calculate a carbon budget for food consumption in Germany. Food production causes inevitably some GHG emissions from biological processes in crop and livestock production, which are hard or impossible to completely avoid in the following decades (Willet et al., 2019). In the future, priorities need to be set between different categories of consumption. As food fulfils our basic need for nutrition, food consumption will need larger shares of the shrinking carbon budget (Clark et al., 2020; Willet et al., 2019), while the budget share of less essential areas, such as leisure, would have to be substantially reduced. In 2050, food is projected to take half of the available carbon budget, as calculated in this report and line with Willet et al. (2019).

The current carbon footprint of German diets has to shrink by 66% by 2030 and 84% by 2050 to achieve the 1.5 target. Every sector of the agri-food systems must change to transform food systems towards a low-carbon track. Changing agricultural production practices, especially take off fields located in drained peatlands, and later stages of the food supply chains is essential, but it can only lead to about 40% of the GHG emission reductions to achieve the 1.5 target. The most impactful single action is to take off fields located in drained peatlands. The rest 60% of the reduction needs to be achieved through demand-side actions, especially changing diets.

To meet our carbon reduction targets we need to make significant dietary changes. These include reducing meat intake by 58% compared with current levels, dairy by 26% and high-carbon footprint beverages, such as coffee, by 30%. By replacing these products with vegetables, fruit and whole grains we can have a more positive effect on the environment and on our health. Fish can provide a good and low-carbon protein source when sourced from low climate impact origins such as no-input aquaculture or small pelagic fisheries. Plant-based diets can also offer the potential for reforestation and rewilding of agricultural areas, as they require less land than meat-based diets.

Certain demographics in Germany, such as young people in cities, are already changing their diet and embracing more plant-based consumption habits (BMEL, 2021) but we have to accelerate these changes. Food choices are shaped by conscious and unconscious decision-making and we can target both to encourage a bigger shift to low-carbon diets. Although changes in diets must be substantial, the transition needs to address gradual shifts towards better food choices such as eating smaller portions of meat and an increased awareness of the health and other benefits of low-carbon diets. Our food environment must also change to enable low-carbon food choices as the default options. However, dietary change is an area where large individual differences exist and where interventions thus need to be tailored to specific target groups.

References

Abrahamse, W. (2020). How to Effectively Encourage Sustainable Food Choices: A Mini-Review of Available Evidence. Frontiers in Psychology, 11. https://doi.org/10.3389/fpsyg.2020.589674

Akenji, L. and Chen H. (2016). A Framework for Shaping Sustainable Lifestyles: Determinants and Strategies.

Akenji, L., Bengtsson, M., Toivio, V., Lettenmeier, M., Fawcett, Tina., Parag, Y., Saheb, Y., Coote, A., Spangenberg, J., Capstick, S., Gore, T., Coscieme, L., Wackernagel, M. & Kenner, D. (2021). 1.5°C Lifestyles: Towards A Fair Consumption Space for All. Hot or Cool Institute, Berlin. https://hotorcool.org/resources/1-5-degree-lifestyles-towards-a-fair-consumption-space-for-all/

Akenji, L. (2022). The (technology) efficiency paradox. https://www.oneplanetnetwork.org/news-and-events/news/technology-efficiency-paradox

Bajželj, B., Richards, K. S., Allwood, J. M., Smith, P., Dennis, J. S., Curmi, E., & Gilligan, C. A. (2014). Importance of food-demand management for climate mitigation. Nature Climate Change, 4(10), 924–929. https://doi.org/10.1038/nclimate2353

Barrett, L. T., Theuerkauf, S. J., Rose, J. M., Alleway, H. K., Bricker, S. B., Parker, M., Petrolia, D. R., & Jones, R. C. (2022). Sustainable growth of non-fed aquaculture can generate valuable ecosystem benefits. Ecosystem Services, 53, 101396. https://doi.org/10.1016/j.ecoser.2021.101396

Bergquist, M., Thiel, M., & Goldberg, M. H. (2023). Field interventions for climate change mitigation behaviors: A second-order meta-analysis. Proceedings of the National Academy of Sciences, 120(13), e2214851120. https://doi.org/10.1073/pnas.2214851120

Beylot, A., Secchi, M., Cerutti, A., Merciai, S., Schmidt, J., & Sala, S. (2019). Assessing the environmental impacts of EU consumption at macro-scale. Journal of Cleaner Production, 216, 382–393. https://doi.org/10.1016/j.jclepro.2019.01.134

BMEL (2016). Klimaschutz in der Land- und Forstwirtschaft sowie den nachgelagerten Bereichen Ernährung und Holzverwendung, Bundesministerium für Ernährung und Landwirtschaft, Wissenschaftlicher Beirat Agrarpolitik, Gutachten. Berlin. https://www.bmel.de/SharedDocs/Downloads/DE/_Ministerium/Beiraete/agrarpolitik/Klimaschutzgutachten_2016.pdf?__blob=publicationFile&v=3

BMEL (2020). Facts and figures on German agricultural exports https://www.bmel.de/EN/topics/international-affairs/foreign-trade-policy/facts-figures-german-agricultural-exports.html

BMEL (2021). Deutschland, wie es isst Der BMEL-Ernährungsreport 2021 https://www.bmel.de/SharedDocs/Downloads/DE/Broschueren/ernaehrungsreport-2021.pdf?__blob=publicationFile&v=5

BMEL (2022). Ernährungswirtschaft, https://www.bmel-statistik.de/ernaehrung-fischerei/versorgungsbilanzen

BMEL (2023). Ökologischer Landbau in Deutschland https://www.bmel.de/DE/themen/landwirtschaft/oekologischer-landbau/oekologischer-landbau-deutschland.html#doc377838bodyText6

Bringezu, S., Banse, M., Ahmann, L., Bezama, N. A., Billig, E., Bischof, R., Blanke, C., Brosowski, A., Brüning, S., Borchers, M., Budzinski, M., Cyffka, K.-F., Distelkamp, M., Egenolf, V., Flaute, M., Geng, N., Gieseking, L., Graß, R., Hennenberg, K., ... Zeug, W. (2021). Pilot report on the monitoring of the German bioeconomy. https://doi.org/10.17170/KOBRA-202201115406

Broekema, R., Tyszler, M., van 't Veer, P., Kok, F. J., Martin, A., Lluch, A., & Blonk, H. T. (2020). Future-proof and sustainable healthy diets based on current eating patterns in the Netherlands. The American Journal of Clinical Nutrition, 112(5), 1338–1347. https://doi.org/10.1093/ajcn/nqaa217

Chan, K., Millinger, M., Schneider, U. A., & Thrän, D. (2022). How diet portfolio shifts combined with land-based climate change mitigation strategies could reduce climate burdens in Germany. Journal of Cleaner Production, 376, 134200. https://doi.org/10.1016/j.jclepro.2022.134200

Chitnis, M., Sorrell, S., Druckman, A., Firth, S. K., & Jackson, T. (2014). Who rebounds most? Estimating direct and indirect rebound effects for different UK socioeconomic groups. Ecological Economics, 106, 12–32. https://doi.org/10.1016/j.ecolecon.2014.07.003

Clark, M., & Tilman, D. (2017). Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice. Environmental Research Letters, 12(6), 064016. https://doi.org/10.1088/1748-9326/aa6cd5

Clark, M. A., Domingo, N. G. G., Colgan, K., Thakrar, S. K., Tilman, D., Lynch, J., Azevedo, I. L., & Hill, J. D. (2020). Global food system emissions could preclude achieving the 1.5° and 2°C climate change targets. Science, 370(6517), 705–708. https://doi.org/10.1126/science.aba7357

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F. N., & Leip, A. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. Nature Food, 2(3), 198–209. https://doi.org/10.1038/s43016-021-00225-9

DGE 2022. Ernahrungskreis. https://www.dge.de/ernaehrungspraxis/vollwertige-ernaehrung/ernaehrungskreis/

de Boer, J., Schösler, H., & Aiking, H. (2014). "Meatless days" or "less but better"? Exploring strategies to adapt Western meat consumption to health and sustainability challenges. Appetite, 76, 120-128. https://doi.org/10.1016/j.appet.2014.02.002

Dräger de Teran, T., Suckow, T. (2021). So schmeckt Zukunft: Der kulinarische Kompass für eine gesunde Erde, Klimaschutz, landwirtschaftliche Fläche und natürliche Lebensräume. WWF Deutschland, Berlin. https://www.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/Landwirtschaft/kulinarische-kompass-klima.pdf

Don, A., Flessa, H., Marx, K., Poeplau, C., Tiemeyer, B. & Osterburg, B. (2018). Die 4-Promille-Initiative „Böden für Ernährungssicherung und Klima": Wissenschaftliche Bewertung und Diskussion möglicher Beiträge in Deutschland. IDEAS Working Paper Series from RePEc.

Drexler, S., Gensior, A., & Don, A. (2021). Carbon sequestration in hedgerow biomass and soil in the temperate climate zone. Regional Environmental Change, 21(3), 74. https://doi.org/10.1007/s10113-021-01798-8

Druckman, A., & Jackson, T. (2016). Understanding Households as Drivers of Carbon Emissions. In R. Clift & A. Druckman (Eds.), Taking Stock of Industrial Ecology (pp. 181–203). Springer International Publishing. https://doi.org/10.1007/978-3-319-20571-7_9

Ecoviaint (2019). Germany: Consumers Shopping for Organic Foods, https://www.ecoviaint.com/germany-consumers-shopping-for-organic-foods/

Edenbrandt, A. K., & Lagerkvist, C. (2021). Is food labelling effective in reducing climate impact by encouraging the substitution of protein sources? Food Policy, 101, 102097. https://doi.org/10.1016/j.foodpol.2021.102097

Eker, S., Garcia, D., Valin, H., & Van Ruijven, B. (2021). Using social media audience data to analyse the drivers of low-carbon diets. Environmental Research Letters, 16(7), 074001. doi: 10.1088/1748-9326/abf770

Eurobarometer (2022). Special Eurobarometer 97.2, https://www.efsa.europa.eu/sites/default/files/corporate_publications/files/eurobarometer22/country-factsheets/eb972_factsheet_de_en.pdf

EuroStat (2022). Organic farming statistics, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Organic_farming_statistics

FAOStat (2021). Food Balances, https://www.fao.org/faostat/en/#data/FBS

Garnett, T., Godde, C., Muller, A., Röös, E., Smith, P., de Boer, I., Ermgassen, E., Herrero, M., Middelaar C., Schader, C. & van Zanten, H. (2017). Grazed and confused?, Food Climate Research Network FCRN, https://tabledebates.org/sites/default/files/2020-10/fcrn_gnc_report.pdf

GBD (2019). Global Burden of Disease Study 2019. Institute for Health Metrics and Evaluation (IHME). https://www.healthdata.org/gbd

Gephart, J. A., Henriksson, P. J. G., Parker, R. W. R., Shepon, A., Gorospe, K. D., Bergman, K., Eshel, G., Golden, C. D., Halpern, B. S., Hornborg, S., Jonell, M., Metian, M., Mifflin, K., Newton, R., Tyedmers, P., Zhang, W., Ziegler, F., & Troell, M. (2021). Environmental performance of blue foods. Nature, 597(7876), 360–365. https://doi.org/10.1038/s41586-021-03889-2

Grethe, H., Martinez, J., Osterburg, B., Taube, F. & Thom, F. (2021). Klimaschutz im Agrar- und Ernährungssystem Deutschlands. Stiftung Klimaneutralität. https://www.stiftung-klima.de/app/uploads/2021/06/2021-06-01-Klimaneutralitaet_Landwirtschaft.pdf

Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., Schlesinger, W. H., Shoch, D., Siikamäki, J. V., Smith, P., Woodbury, P., Zganjar, C., Blackman, A., Campari, J., Conant, R. T., Delgado, C., Elias, P., Gopalakrishna, T., Hamsik, M. R., … Fargione, J. (2017). Natural climate solutions. Proceedings of the National Academy of Sciences, 114(44), 11645–11650. https://doi.org/10.1073/pnas.1710465114

Hallström, E., Carlsson-Kanyama, A., & Börjesson, P. (2015). Environmental impact of dietary change: A systematic review. Journal of Cleaner Production, 91, 1–11. https://doi.org/10.1016/j.jclepro.2014.12.008

Harguess, J. M., Crespo, N. C., & Hong, M. Y. (2020). Strategies to reduce meat consumption: A systematic literature review of experimental studies. Appetite, 144, 104478. https://doi.org/10.1016/j.appet.2019.104478

Hayek, M. N., Harwatt, H., Ripple, W. J., & Mueller, N. D. (2020). The carbon opportunity cost of animal-sourced food production on land. Nature Sustainability, 4(1), 21–24. https://doi.org/10.1038/s41893-020-00603-4

IPCC (2018). Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate.

IPCC (2023). Synthesis report of the IPCC sixth assessment report (AR6). https://report.ipcc.ch/ar6syr/pdf/IPCC_AR6_SYR_LongerReport.pdf

Jacobs, A., Flessa, H., & Don, A. (2018). Landwirtschaftlich genutzte Böden in Deutschland—Ergebnisse der Bodenzustandserhebung. Johann Heinrich von Thünen-Institut. https://doi.org/10.3220/REP1542818391000

Jardim, T. V., Mozaffarian, D., Abrahams-Gessel, S., Sy, S., Lee, Y., Liu, J., Huang, Y., Rehm, C., Wilde, P., Micha, R., & Gaziano, T. A. (2019). Cardiometabolic disease costs associated with suboptimal diet in the United States: A cost analysis based on a microsimulation model. PLOS Medicine, 16(12), e1002981. https://doi.org/10.1371/journal.pmed.1002981

Kanerva, M. (2013). Meat consumption in Europe: Issues, trends and debates. Universität Bremen, ARTEC Forschungszentrum Nachhaltigkeit. https://media.suub.uni-bremen.de/bitstream/elib/4865/1/187_paper.pdf

Kolbe, K. (2020). Mitigating climate change through diet choice: Costs and CO_2 emissions of different cookery book-based dietary options in

Germany. Advances in Climate Change Research, 11(4), 392–400. https://doi.org/10.1016/j.accre.2020.11.003

Krauss, M., Wiesmeier, M., Don, A., Cuperus, F., Gattinger, A., Gruber, S., Haagsma, W. K., Peigné, J., Palazzoli, M. C., Schulz, F., van der Heijden, M. G. A., Vincent-Caboud, L., Wittwer, R. A., Zikeli, S., & Steffens, M. (2022). Reduced tillage in organic farming affects soil organic carbon stocks in temperate Europe. Soil and Tillage Research, 216, 105262. https://doi.org/10.1016/j.still.2021.105262

Krizanova, J., Rosenfeld, D. L., Tomiyama, A. J., & Guardiola, J. (2021). Pro-environmental behavior predicts adherence to plant-based diets. Appetite, 163, 105243. https://doi.org/10.1016/j.appet.2021.105243

Kwasny, T., Dobernig, K., & Riefler, P. (2022). Towards reduced meat consumption: A systematic literature review of intervention effectiveness, 2001–2019. Appetite, 168, 105739. https://doi.org/10.1016/j.appet.2021.105739

Lacroix, K., Goldberg, M. H., Marlon, J. R., Rosenthal, S. A., Ballew, M. T., Wang, X., ... Leiserowitz, A. (2022, February 22). PLANTS: A scalable survey tool for identifying groups willing to adopt plant-based diets. https://doi.org/10.31219/osf.io/hkcvx

Laurent, E., Battaglia, F., Marchiori, G., Galli A., Janoo, A., Munteanu, R. & Sommer, C. (2021). Five Pathways Toward Health-Environment Policy in a Wellbeing Economy. WEAll Policy Paper, Wellbeing Economy Alliance. https://weall.org/wp-content/uploads/WEAll-POLICY-PAPER-Health-and-Environment_3August-1.pdf

Lea, E. J., Crawford, D., & Worsley, A. (2006). Public views of the benefits and barriers to the consumption of a plant-based diet. European Journal of Clinical Nutrition, 60(7), 828-837. https://doi.org/10.1038/sj.ejcn.1602387

Mazac, R., Meinilä, J., Korkalo, L., Järviö, N., Jalava, M., & Tuomisto, H. L. (2022). Incorporation of novel foods in European diets can reduce global warming potential, water use and land use by over 80%. Nature Food, 3(4), 286–293. https://doi.org/10.1038/s43016-022-00489-9

Mathur, M. B., Peacock, J., Reichling, D. B., Nadler, J., Bain, P. A., Gardner, C. D., & Robinson, T. N. (2021). Interventions to reduce meat consumption by appealing to animal welfare: Meta-analysis and evidence-based recommendations. Appetite, 164, 105277. https://doi.org/10.1016/j.appet.2021.105277

Meier, T., & Christen, O. (2012). Gender as a factor in an environmental assessment of the consumption of animal and plant-based foods in Germany. The International Journal of Life Cycle Assessment, 17(5), 550–564. https://doi.org/10.1007/s11367-012-0387-x

Michel, F., Hartmann, C., & Siegrist, M. (2021). Consumers' associations, perceptions and acceptance of meat and plant-based meat alternatives. Food Quality and Preference, 87, 104063. https://doi.org/10.1016/j.foodqual.2020.104063

Miehe, R., Scheumann, R., Jones, C. M., Kammen, D. M., & Finkbeiner, M. (2016). Regional carbon footprints of households: A German case study. Environment, Development and Sustainability, 18(2), 577–591. https://doi.org/10.1007/s10668-015-9649-7

Miki, A. J., Livingston, K. A., Karlsen, M. C., Folta, S. C., & McKeown, N. M. (2020). Using Evidence Mapping to Examine Motivations for Following Plant-Based Diets. Current Developments in Nutrition, 4(3), nzaa013. https://doi.org/10.1093/cdn/nzaa013

Ohlau, M., Spiller, A., & Risius, A. (2022). Plant-Based Diets Are Not Enough? Understanding the Consumption of Plant-Based Meat Alternatives Along Ultra-processed Foods in Different Dietary Patterns in Germany. Frontiers in Nutrition, 9. https://doi.org/10.3389/fnut.2022.852936

Paris, J. M. G., Falkenberg, T., Nöthlings, U., Heinzel, C., Borgemeister, C., & Escobar, N. (2022). Changing dietary patterns is necessary to improve the sustainability of Western diets from a One Health perspective. Science of The Total Environment, 811, 151437. https://doi.org/10.1016/j.scitotenv.2021.151437

Parker, R. W. R., Blanchard, J. L., Gardner, C., Green, B. S., Hartmann, K., Tyedmers, P. H., & Watson, R. A. (2018). Fuel use and greenhouse gas emissions of world fisheries. Nature Climate Change, 8(4), 333–337. https://doi.org/10.1038/s41558-018-0117-x

Pohjolainen, P., Vinnari, M. and Jokinen, P. (2015), „Consumers' perceived barriers to following a plant-based diet", British Food Journal, Vol. 117 No. 3, pp. 1150-1167. https://doi.org/10.1108/BFJ-09-2013-0252

Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. Science, 360(6392), 987–992. https://doi.org/10.1126/science.aaq0216

Prognos, Öko-Institut, Wuppertal-Institut. 2021: Klimaneutrales Deutschland 2045. Wie Deutschland seine Klimaziele schon vor 2050 erreichen kann Zusammenfassung im Auftrag von Stiftung Klimaneutralität, Agora Energiewende und Agora Verkehrswende

Ranger, N., Gohar, L. K., Lowe, J. A., Raper, S. C. B., Bowen, A., & Ward, R. E. (2012). Is it possible to limit global warming to no more than 1.5°C?: A letter. Climatic change, 111(3-4), 973-981. https://doi.org/10.1007/s10584-012-0414-8

Rasche, L., Schneider, U. A., & Steinhauser, J. (2023). A stakeholders' pathway towards a future land use and food system in Germany. Sustainability Science, 18(1), 441–455. https://doi.org/10.1007/s11625-022-01212-0

Reipurth, M. F., Hørby, L., Gregersen, C. G., Bonke, A., & Perez Cueto, F. J. (2019). Barriers and facilitators towards adopting a more plant-based diet in a sample of Danish consumers. Food Quality and Preference, 73, 288-292. https://doi.org/10.1016/j.foodqual.2018.10.012

Riggers, C., Poeplau, C., Don, A., Frühauf, C., & Dechow, R. (2021). How much carbon input is required to preserve or increase projected soil organic carbon stocks in German croplands under climate change? Plant and Soil, 460(1–2), 417–433. https://doi.org/10.1007/s11104-020-04806-8

Ritchie, H. & Roser, M. (2021). Fish and ovefishing: environmental footprint of fishing. Published online: https://ourworldindata.org/fish-and-overfishing

Roe, S., Streck, C., Beach, R., Busch, J., Chapman, M., Daioglou, V., Deppermann, A., Doelman, J., Emmet‐Booth, J., Engelmann, J., Fricko, O., Frischmann, C., Funk, J., Grassi, G., Griscom, B., Havlik, P., Hanssen, S., Humpenöder, F., Landholm, D., … Lawrence, D. (2021). Land‐based measures to mitigate climate change: Potential and feasibility by country. Global Change Biology, 27(23), 6025–6058. https://doi.org/10.1111/gcb.15873

Roe, S., Streck, C., Obersteiner, M., Frank, S., Griscom, B., Drouet, L., Fricko, O., Gusti, M., Harris, N., Hasegawa, T., Hausfather, Z., Havlík, P., House, J., Nabuurs, G.-J., Popp, A., Sánchez, M. J. S., Sanderman, J., Smith, P., Stehfest, E., & Lawrence, D. (2019). Contribution of the land sector to a 1.5 °C world. Nature Climate Change, 9(11), 817–828. https://doi.org/10.1038/s41558-019-0591-9

Rowntree, J. E., Stanley, P. L., Maciel, I. C. F., Thorbecke, M., Rosenzweig, S. T., Hancock, D. W., Guzman, A., & Raven, M. R. (2020). Ecosystem Impacts and Productive Capacity of a Multi-Species Pastured Livestock System. Frontiers in Sustainable Food Systems, 4, 544984. https://doi.org/10.3389/fsufs.2020.544984

Sala, S., Beylot, A., Corrado, S., Crenna, E., Sanyé-Mengual, E. & Secchi, M. (2019). Indicators and assessment of the environmental impact of EU consumption. Publications Office. European Commission. Joint Research Centre. https://data.europa.eu/doi/10.2760/403263

Scheelbeek, P., Green, R., Papier, K., Knuppel, A., Alae-Carew, C., Balkwill, A., Key, T. J., Beral, V., & Dangour, A. D. (2020). Health impacts and environmental footprints of diets that meet the Eatwell Guide recommendations: Analyses of multiple UK studies. BMJ Open, 10(8), e037554. https://doi.org/10.1136/bmjopen-2020-037554

Scherer, L., Rueda, O., & Smetana, S. (2023). Environmental impacts of meat and meat replacements. In Meat and Meat Replacements (pp. 365–397). Elsevier. https://doi.org/10.1016/B978-0-323-85838-0.00012-2

Schmidt, T., Schneider, F., Leverenz, D., Hafner, G., Schmidt, T., Schneider, F., Leverenz, D., & Hafner, G. (2019). Lebensmittelabfälle in Deutschland – Baseline 2015 –. https://doi.org/10.22004/AG.ECON.294004

Searchinger, T., Waite, R., Hanson, C., Ranganathan, J., Dumas, P. & Matthews, E. (2018). Creating a Sustainable Food Future: A Menu of Solutions to Feed Nearly 10 Billion People by 2050. World Resource Institute.

Smetana, S., Mathys, A., Knoch, A., & Heinz, V. (2015). Meat alternatives: Life cycle assessment of most known meat substitutes. The International Journal of Life Cycle Assessment, 20(9), 1254–1267. https://doi.org/10.1007/s11367-015-0931-6

Sparkman, G., & Walton, G. M. (2017). Dynamic Norms Promote Sustainable Behavior, Even if It Is Counternormative. Psychological Science. https://doi.org/10.1177/0956797617719950

Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Bodirsky, B. L., Lassaletta, L., de Vries, W., Vermeulen, S. J., Herrero, M., Carlson, K. M., Jonell, M., Troell, M., DeClerck, F., Gordon, L. J., Zurayk, R., Scarborough, P., Rayner, M., Loken, B., Fanzo, J., … Willett, W. (2018). Options for keeping the food system within environmental limits. Nature, 562(7728), 519–525. https://doi.org/10.1038/s41586-018-0594-0

Springmann, M., Godfray, H. C. J., Rayner, M., & Scarborough, P. (2016). Analysis and valuation of the health and climate change cobenefits of dietary change. Proceedings of the National Academy of Sciences, 113(15), 4146–4151. https://doi.org/10.1073/pnas.1523119113

Stanley, P. L., Rowntree, J. E., Beede, D. K., DeLonge, M. S., & Hamm, M. W. (2018). Impacts of soil carbon sequestration on life cycle greenhouse gas emissions in Midwestern USA beef finishing systems. Agricultural Systems, 162, 249–258. https://doi.org/10.1016/j.agsy.2018.02.003

Stein-Bachinger, K., Gottwald, F., Haub, A., & Schmidt, E. (2021). To what extent does organic farming promote species richness and abundance in temperate climates? A review. Organic Agriculture, 11(1), 1–12. https://doi.org/10.1007/s13165-020-00279-2

Sun, Z., Scherer, L., Tukker, A., Spawn-Lee, S. A., Bruckner, M., Gibbs, H. K., & Behrens, P. (2022). Dietary change in high-income nations alone can lead to substantial double climate dividend. Nature Food, 3(1), 29–37. https://doi.org/10.1038/s43016-021-00431-5

Taufik, D., Verain, M. C., Bouwman, E. P., & Reinders, M. J. (2019). Determinants of real-life behavioural interventions to stimulate more plant-based and less animal-based diets: A systematic review. Trends in Food Science & Technology, 93, 281-303. https://doi.org/10.1016/j.tifs.2019.09.019

Tilman, D., & Clark, M. (2014). Global diets link environmental sustainability and human health. Nature, 515(7528), 518–522. https://doi.org/10.1038/nature13959

Treu, H., Nordborg, M., Cederberg, C., Heuer, T., Claupein, E., Hoffmann, H., & Berndes, G. (2017). Carbon footprints and land use of conventional and organic diets in Germany. Journal of Cleaner Production, 161, 127–142. https://doi.org/10.1016/j.jclepro.2017.05.041

United Nations. (2017). "World Population Prospects: The 2017 Revision." June 21, 2017. https://population.un.org/wpp/.

van Dooren, C., Marinussen, M., Blonk, H., Aiking, H., & Vellinga, P. (2014). Exploring dietary guidelines based on ecological and nutritional values: A comparison of six dietary patterns. Food Policy, 44, 36–46. https://doi.org/10.1016/j.foodpol.2013.11.002

Van Loo, E. J., Hoefkens, C., & Verbeke, W. (2017). Healthy, sustainable and plant-based eating: Perceived (mis)match and involvement-based consumer segments as targets for future policy. Food Policy, 69, 46-57. https://doi.org/10.1016/j.foodpol.2017.03.001

van Vuuren, D. P., Stehfest, E., Gernaat, D. E. H. J., van den Berg, M., Bijl, D. L., de Boer, H. S. Analysis, E. S. (2018). Alternative pathways to the

1.5 °C target reduce the need for negative emission technologies. Nature climate change, 8(5), 391-397. https://doi.org/10.1038/s41558-018-0119-8

Westhoek, H., Lesschen, J. P., Rood, T., Wagner, S., De Marco, A., Murphy-Bokern, D., Leip, A., van Grinsven, H., Sutton, M. A., & Oenema, O. (2014). Food choices, health and environment: Effects of cutting Europe's meat and dairy intake. Global Environmental Change, 26, 196–205. https://doi.org/10.1016/j.gloenvcha.2014.02.004

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L. J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J. A., De Vries, W., Majele Sibanda, L., ... Murray, C. J. L. (2019). Food in the Anthropocene: The EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet, 393(10170), 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4

Ziegler, F., Hornborg, S., Green, B. S., Eigaard, O. R., Farmery, A. K., Hammar, L., Hartmann, K., Molander, S., Parker, R. W. R., Skontorp Hognes, E., Vázquez-Rowe, I., & Smith, A. D. M. (2016). Expanding the concept of sustainable seafood using Life Cycle Assessment. Fish and Fisheries, 17(4), 1073–1093. https://doi.org/10.1111/faf.12159

Ziegler, R., Wichtmann, W., Abel, S., Kemp, R., Simard, M., & Joosten, H. (2021). Wet peatland utilisation for climate protection – An international survey of paludiculture innovation. Cleaner Engineering and Technology, 5, 100305. https://doi.org/10.1016/j.clet.2021.100305