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An analysis of the environmental effects and policy implications of dietary change in Germany

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Vorwort

Prof. Dr. Dirk Messner, Präsident des Umweltbundesamtes
Foto: Susanne Kambor, Umweltbundesamt

Liebe Leser*innen,

über die Umwelt- und Klimawirkungen unserer Ernährungsentscheidungen wird mittlerweile intensiv diskutiert – und das zu Recht, wie dieser Bericht einmal mehr untermauert. Denn unsere derzeitige Ernährungsweise in Deutschland ist nicht mit der ökologischen Tragfähigkeit des Planeten vereinbar. Insbesondere dem Anteil tierischer Lebensmittel kommt eine Schlüsselrolle für die Erreichung von zukunftsweisenden Ernährungsweisen zu, weil die Reduktion der Nutztierhaltung auf ein nachhaltiges Maß dringend benötigte umweltpolitische Handlungsoptionen eröffnet: Die landwirtschaftlichen Flächen, die derzeit für die Futtergewinnung belegt werden, könnten wir für effektiven Klima- und Biodiversitätsschutz nutzen und die erhebliche Menge an Treibhausgasemissionen, die mit der Tierhaltung verbunden ist, könnten verringert werden - um nur zwei wichtige Chancen zu nennen.

Bisher gibt es nur wenige Veröffentlichungen, die konkrete Daten zu den Auswirkungen von Ernährungsumstellungen in Deutschland ausweisen. Häufig werden diese nur aggregiert angegeben, z.B. für Länder mit hohem Durchschnittseinkommen. Diese Lücke versucht das vorliegende Gutachten zu schließen, indem es die Ergebnisse für Deutschland aus globalen Modellierungsstudien, die der Autor gemeinsam mit Kolleginnen und Kollegen durchgeführt und aggregiert publiziert hat, öffentlich zugänglich macht. Dazu gehören auch die Ergebnisse der 2018 in der Fachzeitschrift *Nature* veröffentlichten Modellierung, die im Rahmen der Arbeiten der renommierten *EAT-Lancet-Kommission zu Gesunden Ernährungsweisen von Nachhaltigen Ernährungssystemen* durchgeführt wurden.

In Bezug auf die Umweltaspekte der Ernährung ist aufgrund der Fülle bereits veröffentlichter wissenschaftlicher Studien bereits klar, dass stärker pflanzenbasierte Ernährungsweisen klimaschonender sind und insbesondere in Kombination mit Verbesserungen der Produktion von Lebensmitteln und der Reduktion der Lebensmittelverschwendung ein äußerst effektiver Hebel zur Abmilderung gleich mehrerer erdsystemrelevanter Umweltprobleme. Doch weitere Fragen müssen noch beantwortet werden, wie diese Studie zeigt.

Genügt es, die Produktion umweltfreundlicher zu machen und den Missstand der Lebensmittelverschwendung zu beheben? Könnten die Planetaren Grenzen eingehalten werden, wenn sich alle Menschen nach den derzeitigen Empfehlungen der Deutschen Gesellschaft für Ernährung ernährten, was eine Reduzierung des Fleischkonsum um 45 bis 70 Prozent bedeuten würde? Und wären die Kosten für Ernährungsweisen nach den Empfehlungen *der EAT-Lancet-Kommission* höher als die unserer derzeitigen Ernährungsweisen?

Dieser Bericht stellt wissenschaftliche Antworten auf diese und weitere aktuell brennende Fragen kompakt zusammen, und zwar im Kontext eines sich äußerst dynamisch entwickelnden (Forschungs-)Themas. Diese Dynamik zeigt sich beispielsweise daran, dass Methoden und Daten zur Quantifizierung von Umweltwirkungen kontinuierlich weiterentwickelt werden und sowohl die EAT-Lancet-Kommission als auch die Deutsche Gesellschaft für Ernährung (DGE) derzeit ihre Empfehlungen überarbeiten. Auch die Berechnungen der Kosten erfolgte auf einer Basis, die die Auswirkungen der Russlandkrise und der diesjährigen und zukünftiger Dürren noch nicht integrieren. Weitere Berechnungen sind daher nötig, um das Ergebnis, dass Ernährungsweisen nach der Planetary Health Diet der EAT-Lancet Kommission ganz überwiegend auch finanziell günstiger als die durchschnittliche Ernährungsweise ist, zu konsolidieren.

Wir wissen daher genug, um aus Umwelt- und Klimasicht für veränderte Ernährungsweisen zu werben, aber müssen weitere Fragen beantworten, denen dieses Gutachten nachgeht, um wirkungsvoll eine erdsystemverträgliche Umstellung unserer Ernährungsgewohnheiten zu unterstützen.

DIRK MESSNER

Abstract: Towards healthy and sustainable diets in Germany

The global food system is neither healthy, nor sustainable. Food production is a major driver of climate change and environmental resource use, whilst consuming unhealthy diets is a leading risk factor for chronic diseases and mortality. It has been estimated that without changes towards healthier and more sustainable dietary patterns, there is little chance of avoiding dangerous levels of climate change and staying within the environmental limits of the food system with regards to land, water, and fertilizer use. Although there is a broad consensus on the long-term need for global dietary changes, much less information is available or accessible at the national level. This report fills this gap by distilling estimates of the environmental and cost impacts of dietary changes for Germany from a series of global modelling studies with regional detail, and by discussing their policy implications.

Kurzbeschreibung: Für eine gesunde und nachhaltige Ernährung in Deutschland

Das globale Ernährungssystem ist weder gesund noch nachhaltig. Die Lebensmittelproduktion ist ein wesentlicher Triebfaktor des Klimawandels und der Nutzung natürlicher Ressourcen. Gleichzeitig ist ungesunde Ernährung ein Hauptrisikofaktor für chronische Krankheiten und vorzeitige Todesfälle. Es wird damit gerechnet, dass es ohne Änderungen hin zu gesünderen und nachhaltigeren Ernährungsmustern kaum eine Chance gibt, gefährliche Ausmaße des Klimawandels zu vermeiden und innerhalb der ökologischen Belastbarkeitsgrenzen des Ernährungssystems in Bezug auf Land, Wasser und Düngemittelverbrauch zu bleiben. Obwohl es einen breiten Konsens über die langfristige Notwendigkeit globaler Ernährungsumstellungen gibt, sind auf nationaler Ebene sehr viel weniger Informationen verfügbar oder zugänglich. Dieser Bericht soll diese Lücke füllen, indem er Schätzungen der Umwelt- und Kostenauswirkungen von Ernährungsumstellungen für Deutschland aus einer Reihe globaler Modellierungsstudien mit regionalen Details zusammenfasst und ihre politischen Implikationen diskutiert.

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BMI	Body Mass Index
BMK	Benchmark
CO_2	Carbon dioxide
CoI	Cost of Illness
DGE	German Nutrition Society
FAO	Food and Agriculture Organization of the United Nations
FBDG	Food-based dietary guidelines
FLX	Flexitarian diets
GHG	Greenhouse gas
NDG	National dietary guidelines
N_2O	Nitrous oxide (laughing gas)
PHD	Planetary Health Diet (synonymous: EAT-Lancet-Diet)
VEG	Vegetarian diets
VGN	Vegan diets
WHO	World Health Organization

Summary

The current food system is environmentally unsustainable. Globally, food production is responsible for a quarter to a third of all greenhouse gas (GHG) emissions and therefore a major driver of climate change. Agriculture occupies more than a third of the Earth's land surface and has led to reductions in forest cover and loss of biodiversity. Farming also uses more than two thirds of all freshwater resources, and the over-application of fertilizers in some regions has led to dead zones in oceans. Without concerted action, the environmental pressures of the food system could increase such that they would exceed key planetary boundaries that define a safe operating space for humanity beyond which Earth's vital ecosystems could become unstable.

At the same time, diets in many parts of the world are not healthy. Imbalanced diets, such as diets low in fruits, vegetables, nuts and whole grains, and high in red and processed meat are a leading risk factor for premature mortality globally and in most regions. In addition to imbalanced diets, other forms of malnutrition exist: about 2 billion people are overweight and obese, 2 billion have nutritional deficiencies, whilst about 800 million are still suffering from hunger due to poverty and poorly developed food systems. As the dietary transition towards more processed and high-value products continues in many regions of the world, many of these dietary health risks are expected to worsen.

Dietary changes towards healthier and more sustainable diets have been highlighted as one of the key strategies for simultaneously reducing the environmental pressures of the food system and the health risks of current dietary patterns. Although there is broad consensus on the long-term need for global dietary changes, much less information is available or accessible at the national level. This report is intended to fill this gap by distilling estimates of the impacts of dietary changes for Germany from a series of global modelling studies with regional detail. The estimates include analyses of the environmental impacts, costs, and policy implications of dietary change at the country level. The main findings are as follows.

The German diet has a significant impact on the environment. The analysis in chapter 1 indicates that German food demand in 2010 was responsible for about 60 million (mega) tonnes of carbon dioxide equivalents ($MtCO_2eq$) of GHG emissions in the form of methane and nitrous oxide emissions, 90 thousand square kilometres (km^2) of cropland use, 1 cubic kilometre (km^3) of freshwater resources from surface and groundwater, 1 trillion (tera) grams of nitrogen (TgN) related to fertilizer application, and 130 billion (giga) grams of phosphorus (GgP) related to fertilizer application. In the absence of dedicated mitigation measures, these environmental impacts of the German diet are projected to increase by 6-25% between 2010 and 2050 due to income-related changes in food demand, such as increases in poultry and dairy consumption and stable consumption of red meat. This impact assessment is conservative and, for example, does not include food-related carbon dioxide emissions, e.g. from land-use changes and energy use. Accounting for those would further increase the environmental impacts of the German food demand.

The demand for animal products is responsible for a significant portion of the German diet's environmental impacts. German demand for animal products was associated with the majority (60-63% in 2010; 59-61% in 2050) of food-related GHG emissions, which is due to those products' low feed-conversion efficiencies, enteric fermentation in ruminants, and manure-related emissions. The feed-related impacts of animal products also contributed to pressures on cropland (39-41% of all food-related impacts in 2010; 40-41% in 2050), nitrogen and phosphorus application (each 31-39% in 2010; 32-35% in 2050), and freshwater use (17-22% in 2010; 22-23% in 2050).

Dietary changes towards more plant-based diets shows the greatest mitigation potential for several environmental domains when compared to other strategies to lower environmental impacts. For example, depending on the ambition of change, adoption of more plant-based diets was associated with reductions in food-related GHG emissions of 29-53% compared to baseline projections for 2050. This was the largest mitigation potential for GHG emissions amongst the options analysed, and it compares to 5-10% for technological improvements at the farm level, and 8-12% for reductions in food loss and waste. Dietary changes had also the greatest mitigation potential for cropland and freshwater use, but technological improvements such as more efficient nutrient recycling showed the greatest mitigation potential for nitrogen and phosphorus application. Compared to current dietary patterns with current production methods, the analysis identified a reduction potential of 63-81% in overall food-related GHG emissions, with greatest values for nutritionally balanced vegan diets and lowest values for flexitarian diets which include low to moderate amounts of animal source foods.

German diets are not sustainable when compared to an equitable global share of environmental resources. The analysis in chapters 1 and 2 shows that if everybody in 2050 ate like a German today, then food-related GHG emissions would exceed the level needed to limit global warming to below 2 degrees Celsius by more than threefold. In addition, the planetary boundary related to a sustainable use of nitrogen would be exceeded by 50% and that of land use by over 30%. This makes German diets incompatible with the Paris Climate Agreement and the Sustainable Development Goals related to land use, biodiversity, and water pollution.

To be environmentally sustainable (and healthy), the German diet would have to become significantly more plant-based. The analysis in chapter 2 (based on waste-adjusted food availability data provided by the FAO) highlights that compared to a dietary pattern that is healthy and environmentally sustainable at a global level, such as the Planetary Health Diet developed by the EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems, the German diet contains more than eight times too much red meat (including beef, lamb, and pork), almost three times too much dairy and sugar, as well as 38% too few fruits and vegetables, 30% too few whole grains, 67% too few nuts, and 95% too few legumes. To adopt a healthy and sustainable diet, red meat consumption would have to be reduced by 88%, and dairy consumption by 62%, whilst fruit and vegetable consumption would have to increase by 62%.

According to our analyses the German food-based dietary guidelines are not globally sustainable and are also less sustainable at the national level as the the more plant-based Planetary Health Diet. The analysis in chapter 2 indicates that adoption of the German food-based dietary guidelines (developed by the German Nutrition Society DGE) would be associated with less reductions in environmental impacts when compared to nutritionally-balanced flexitarian, pescatarian, vegetarian or vegan dietary patterns that are in line with the Planetary Health Diet recommendations of the EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems. When the DGE recommendations would be adopted globally, the planetary boundaries of climate change, land use, water use, and nitrogen application would be transgressed due to insufficient stringency of the recommendation for red meat and dairy.

Many healthy and sustainable dietary patterns are more affordable for consumers than the current German diet. The analysis in chapter 3 indicates that, based on current prices in 2017, the cost savings could range from 6% for flexitarian diets, over 21-25% for vegetarian diets, to 15-28% for vegan diets. Pescatarian diets were 8-11% more expensive than current diets. The cost advantage of the healthy and sustainable dietary patterns further increased when considering the full costs of diets. Accounting for the costs of climate change would increase the cost of the German diet by a 10% in 2010, raising to 15% in 2030, and by almost fourfold to 37%

in 2050. Considering public health costs of unhealthy eating patterns would further increase these numbers. All of the more plant-based dietary patterns were associated with significantly less increases in those external costs.

Taxing foods according to their GHG emissions could incentivise dietary changes towards healthier, more sustainable, and more affordable diets, whilst raising revenues that could further support food-system transformation. The analysis in chapter 4 indicates that GHG taxes would be greatest for animal products, in particular beef (58% increase in prices according to this analysis), and negligible for nutritious plant-based products. Analysis of these fiscal policies suggested that environmental taxation of food products could result in environmental benefits, whilst raising public funds that could be used, for example, to support low-income households in changing diets and incentivise farmers to diversify production.

Reforming agricultural subsidies at the EU level provides another opportunity to incentivise and support a food system transition towards healthier and more sustainable food systems. The analysis in chapter 5 indicates that at present half of agricultural transfer payments in the EU are used to produce meat or dairy, both foods with high environmental impacts. Making agricultural subsidies conditional on producing foods with beneficial health and environmental characteristics (such as fruits, vegetables, legumes, and nuts) could increase their production by up to 40% and their consumption by up to 20%, displacing in each case commodities that are less healthy and more environmentally harmful. As a result, greenhouse gas emissions could be reduced by about 4%.

The analyses summarised in this report made use of common and accepted modelling frameworks related to foods systems, dietary intake, and the related environmental and cost impacts. Whilst each estimate is subject to model-based uncertainty, **the general direction of travel is clear:**

- The current dietary choices of Germans are not sustainable.
- Dietary changes towards well-composed, more plant-based dietary patterns that are in line science-based recommendations for a Planetary Health Diet (ranging from low-meat flexitarian diets to completely plant-based vegan diets) are likely to be healthier, more affordable, and environmentally sustainable.
- Population-level adoption of healthy and more sustainable dietary patterns require decisive and coherent policies across the food chain, including:
    - a reform of national dietary guidelines,
    - the provision of price incentives for consumers that account for the environmental impacts of foods, as well as
    - an environmentally sensitive reform of agricultural subsidies.

Zusammenfassung

Das derzeitige Ernährungssystem ist ökologisch nicht nachhaltig. Weltweit ist die Lebensmittelproduktion für ein Viertel bis ein Drittel aller Treibhausgasemissionen verantwortlich und damit ein wesentlicher Treiber des Klimawandels. Die Landwirtschaft nimmt mehr als ein Drittel der Landoberfläche der Erde ein und hat zu einer Verringerung der Waldbedeckung und zum Verlust der biologischen Vielfalt geführt. Die Landwirtschaft verbraucht auch mehr als zwei Drittel aller Süßwasserressourcen, und der übermäßige Einsatz von Düngemitteln hat in einigen Regionen bereits zu sauerstoffarmen Zonen in den Meeren und Ozeanen (sogenannten "tote Zonen") geführt. Ohne konzentrierte Maßnahmen könnten die Umweltbelastungen des Ernährungssystems so zunehmen, dass sie die essenziellen planetare Grenzen überschreiten würden, die einen sicheren Handlungsraum für die Menschheit definieren, und jenseits dessen die lebenswichtigen Ökosysteme der Erde instabil werden könnten.

Gleichzeitig ist die Ernährung in vielen Teilen der Welt ungesund. Eine unausgewogene Ernährung, wie z. B. eine Ernährung mit wenig Obst, Gemüse, Nüssen und Vollkornprodukten und einem hohen Anteil an rotem und verarbeitetem Fleisch, ist weltweit und in den meisten Regionen ein Hauptrisikofaktor für vorzeitige Sterblichkeit. Neben unausgewogener Ernährung gibt es weitere Formen der Mangelernährung: etwa 2 Milliarden Menschen sind übergewichtig und fettleibig, 2 Milliarden leiden an Mangelernährung, während etwa 800 Millionen aufgrund von Armut und schlecht ausgebauten Ernährungssystemen noch immer an Hunger leiden. Da in vielen Regionen der Welt die Ernährungsveränderung hin zu stärker verarbeiteten Produkten voranschreitet, wird erwartet, dass sich viele dieser ernährungsbedingten Gesundheitsrisiken verschärfen werden.

Gesündere und nachhaltigere Ernährungsweisen werden als Schlüsselstrategie gesehen, um gleichzeitig die Umweltbelastungen des Ernährungssystems und die Gesundheitsrisiken der derzeitigen Ernährungsgewohnheiten zu verringern. Auf Basis globaler und überregionaler Daten hat sich ein breiter wissenschaftlicher Konsens über die langfristige Notwendigkeit globaler Ernährungsumstellungen herausgebildet. Auf nationaler Ebene sind bisher sehr viel weniger Informationen verfügbar oder zugänglich. Dieses Gutachten soll diese Lücke schließen, indem es Schätzungen der Auswirkungen eines Ernährungswandels für Deutschland aus einer Reihe globaler Modellierungsstudien mit regionalen Details zusammenführt. Die Schätzungen umfassen Analysen der Umweltauswirkungen, Kosten und politischen Implikationen von Ernährungsumstellungen auf Länderebene. Die Hauptergebnisse sind wie folgt.

Die Ernährungsgewohnheiten in Deutschland haben erhebliche Auswirkungen auf die Umwelt. Die Analyse in Kapitel 1 zeigt, dass die deutsche Lebensmittelnachfrage im Jahr 2010 für Treibhausgasemissionen von etwa 60 Millionen (Mega) Tonnen Kohlendioxidäquivalente ($MtCO_2eq$) in Form von Methan und Lachgas verantwortlich war, Ackerlandnutzung von 90.000 Quadratkilometer (km^2), Süßwasserressourcen von 1 Kubikkilometer (km^3) aus Oberflächen- und Grundwasser, und Düngemittelanwendung von 1 Billion (Tera) Gramm (TgN) Stickstoff und 130 Milliarden (Giga) Gramm Phosphor (GgP). Ohne gezielte Minderungsmaßnahmen werden diese Umweltauswirkungen der deutschen Ernährung zwischen 2010 und 2050 um 6-25% steigen, insbesondere aufgrund von einkommensbedingten Veränderungen der Lebensmittelnachfrage, wie z. B. einem Anstieg des Geflügel- und Milchkonsums und einem stabilen Konsum von rotem Fleisch. Diese Folgenabschätzung ist konservativ und bezieht beispielsweise nicht lebensmittelbedingte Kohlendioxidemissionen, z.B. aus Landnutzungsänderungen und Energieverbrauch, mit ein. Eine Berücksichtigung dieser würde die Umweltauswirkungen der deutschen Lebensmittelnachfrage weiter erhöhen.

Der nationale Konsum tierischer Produkte ist für einen erheblichen Teil der Umweltauswirkungen der deutschen Ernährung verantwortlich. Die deutsche Nachfrage nach tierischen Produkten verursachte den Großteil (60-63% im Jahr 2010; 59-61% im Jahr 2050) der lebensmittelbedingten Treibhausgasemissionen, was auf die geringe Futterverwertungseffizienz dieser Produkte, die enterische Fermentation bei Wiederkäuern, und düngerbedingte Emissionen zurückzuführen ist. Die mit dem Futter verbundenen Auswirkungen tierischer Produkte trugen auch einen erheblichen Teil zur Nachfrage von Ackerland (39-41% aller ernährungsbedingten Auswirkungen im Jahr 2010; 40-41% im Jahr 2050), Stickstoff- und Phosphorausbringung (jeweils 31-39% im Jahr 2010; 32 -35% im Jahr 2050) und Süßwasserverbrauch (17-22% im Jahr 2010; 22-23% im Jahr 2050) bei.

Eine Umstellung in Richtung pflanzbetonteren Ernährungsweisen haben das größte Potenzial zur Verminderung von Umwelteinflüssen im Vergleich zu anderen Verminderungsstrategien. Um die Wirkung der Strategien abzuschätzen, wurde zunächst eine Fortsetzung bisheriger Trends bis in das Jahr 2050 angenommen und dieses Standard-Szenario mit Szenarien verglichen, in denen Maßnahmen zur Verminderung der Umweltbelastung (i.e. stärker pflanzenbasierte Ernährungsweisen, Reduktion der Lebensmittelverschwendung und -abfälle und Verbesserungen in der Lebensmittelproduktion) angenommen wurden. Beispielsweise war die Umstellung auf eine stärker pflanzenbasierte Ernährung je nach Ambitionsniveau mit einer Reduzierung der lebensmittelbedingten Treibhausgasemissionen um 29-53% im Vergleich zu den Standardprognosen für 2050 verbunden. Dies war das größte Minderungspotenzial für Treibhausgasemissionen unter den analysierten Optionen: auf 5-10% kamen technologische Verbesserungen in der Landwirtschaft, und auf 8-12% die Reduzierung von Lebensmittelverlusten und -verschwendung. Ernährungsumstellungen hatten auch das größte Minderungspotenzial für die Nutzung von Ackerland und Süßwasser, aber technologische Verbesserungen wie ein effizienteres Nährstoffrecycling zeigten das größte Minderungspotenzial für die Stickstoff- und Phosphoranwendung. Im Vergleich zu aktuellen Ernährungsmustern mit aktuellen Produktionsmethoden und dem aktuellen Ausmaß an Lebensmittelabfällen und -verschwendung identifizierte die Analyse ein Reduktionspotenzial von 63-81% der lebensmittelbedingten Treibhausgasemissionen, wobei die größte Reduktion mit einer ausgewogene und komplett pflanzliche Ernährung assoziiert war, und die niedrigste Reduktion mit flexitarischen Ernährungsweisen, die geringe Mengen tierischer Lebensmittel beinhalten.

Die durchschnittliche Ernährungsweise in Deutschland ist bezogen auf eine gerechte Aufteilung von weltweiten Umweltressourcen nicht nachhaltig. Die Analyse in den Kapiteln 1 und 2 zeigt: würden sich im Jahr 2050 alle Menschen weltweit so ernähren wie heute die Deutschen, dann würden allein die ernährungsbedingten Treibhausgasemissionen das zur Begrenzung der Erderwärmung auf unter 2 Grad Celsius notwendige Maß um mehr als das Dreifache übersteigen. Zudem würden die planetaren Grenzen bezüglich einer nachhaltigen Nutzung von Stickstoff um 50% und die der Landnutzung um über 30% überschritten. Dies macht die derzeitige Ernährungsweise in Deutschland unvereinbar mit dem Pariser Klimaabkommen und den Zielen für nachhaltige Entwicklung (Sustainable Development Goals) in Bezug auf Landnutzung, Biodiversität und Wasserverschmutzung.

Um umweltverträglich (und gesund) zu sein, müsste die Ernährung in Deutschland deutlich pflanzenbasierter werden. Die Analyse in Kapitel 2 (basierend auf FAO-Daten zur Verfügbarkeit von Lebensmittel, von denen Schätzungen zur Lebensmittelverschwendung abgezogen wurden) zeigt, dass im Vergleich zu einem Ernährungsmuster, das auf globaler Ebene gesund und umweltverträglich ist (die von der EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems entwickelte Planetary Health Diet), die deutsche Ernährung mehr als achtmal zu viel rotes Fleisch (einschließlich Rind, Lamm und Schwein), fast dreimal zu viel Milchprodukte und Zucker sowie 38% zu wenig Obst und Gemüse, 30% zu wenig Vollkornprodukte, 67% zu wenig Nüsse und 95% zu wenig Hülsenfrüchte enthält. Für eine gesunde und nachhaltige Ernährung müsste der Konsum von rotem Fleisch um 88% und der Konsum von Milchprodukten um 62% reduziert werden, während der Konsum von Obst und Gemüse um 62% steigen müsste.

Die derzeitigen Ernährungsempfehlungen für Deutschland sind nicht global nachhaltig und auch auf nationaler Ebene mit einer größeren Umweltbelastung verbunden als die stärker pflanzenbasierte Planetary Health Diet. Die Analyse in Kapitel 2 zeigt, dass die aktuellen deutschen lebensmittelbasierten Ernährungsempfehlungen (entwickelt von der Deutschen Gesellschaft für Ernährung DGE) im Vergleich zu ausgewogenen flexitarischen, pescetarischen, vegetarischen oder veganen Ernährungsmustern, die im Einklang mit den Empfehlungen der Planetary Health Diet der EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems sind, mit einer geringeren Verringerung der Umweltauswirkungen verbunden wären. Bei einer globalen Annahme der DGE-Empfehlungen würden die ernährungsbezogenen planetaren Grenzen des Klimawandels, der Landnutzung, der Wassernutzung und der Stickstoffanwendung überschritten, insbesondere weil die Empfehlungen für rotes Fleisch und Milchprodukte nicht stringent genug sind.

Viele gesunde und nachhaltige Ernährungsmuster sind für Verbraucher erschwinglicher als die aktuelle deutsche Ernährungsweise. Die Analyse in Kapitel 3 zeigt, dass die Kosteneinsparungen basierend auf Preisen im Jahr 2017 von 6% für eine flexitarische Ernährung über 21-25% für eine vegetarische Ernährung bis hin zu 15-28% für vegane Ernährung reichen können. Eine pescetarische Ernährung war 8-11% teurer als die derzeitige Ernähungsweise. Bezieht man zusätzlich die gesellschaftlichen Kosten mit ein, wird der Kostenvorteil der gesunden und nachhaltigen Ernährungsmuster noch deutlicher: die Berücksichtigung der Kosten des Klimawandels würde die Kosten der deutschen Ernährungsweise um 10% im Jahr 2010, 15% im Jahr 2030 und 37% im Jahr 2050 erhöhen. Alle pflanzenbasierteren Ernährungsmuster waren mit einem deutlich geringeren Anstieg dieser externen Kosten verbunden.

Die Besteuerung von Lebensmitteln nach ihren Treibhausgasemissionen könnte Anreize für eine Ernährungsumstellung hin zu einer gesünderen, nachhaltigeren und erschwinglicheren Ernährung schaffen und gleichzeitig die Einnahmen steigern, die die Transformation des Ernährungssystems weiter unterstützen könnten. Die Modellierung dieser steuerpolitischen Maßnahmen in Kapitel 4 deutet darauf hin, dass die auf Treibhausgasemissionen basierende Besteuerung für tierische Produkte, insbesondere Rindfleisch (58% Preissteigerung gemäß dieser Analyse), am höchsten und für pflanzliche Produkte vernachlässigbar wären. Die Analyse dieser Steuerpolitik deutete darauf hin, dass eine Umweltbesteuerung von Nahrungsmitteln zu Umweltvorteilen führen und gleichzeitig öffentliche Mittel aufbringen könnte, die beispielsweise zur Unterstützung einkommensschwacher Haushalte bei der Umstellung der Ernährung und als Anreiz für Landwirte und Landwirtinnen zur Diversifizierung der Produktion verwendet werden könnten.

Die Reform der Agrarsubventionen auf EU-Ebene bietet eine weitere Gelegenheit, Anreize für ein gesünderes und nachhaltigeres Ernährungssystem zu schaffen. Die Analyse in Kapitel 5 zeigt, dass derzeit (basierend auf Daten von 2017) die Hälfte der landwirtschaftlichen Subventionen in der EU für die Produktion von Fleisch oder Milchprodukten verwendet werden, also Lebensmittel, die mit erheblichen Umwelteinflüssen verbunden sind. Die Bindung von Agrarsubventionen an die Produktion von Lebensmitteln mit gesundheits- und umweltfördernden Eigenschaften (wie Obst, Gemüse, Hülsenfrüchte und Nüsse) könnte die

Produktion dieser Lebensmittel um bis zu 40% und deren Konsum um bis zu 20% steigern und gleichzeitig ungesunde und umweltschädlichere Lebensmittel verdrängen. Dadurch könnten die Treibhausgasemissionen um etwa 4% gesenkt werden.

Die in diesem Bericht zusammengefassten Analysen verwendeten gängige und akzeptierte Modellierungsmethoden in Bezug auf Ernährungssysteme und Ernähung, und die damit verbundenen Umwelt- und Kostenauswirkungen. Während jede Schätzung modellbasierten Unsicherheiten unterliegt, sind **die allgemeinen Schlußfolgerungen** klar:

- ► Die aktuellen Ernährungsgewohnheiten in Deutschland sind nicht nachhaltig.
- ► Ernährungsumstellungen hin zu ausgewogenen, mehr pflanzenbasierten Ernährungsmustern, die den Empfehlungen der Planetary Health Diet (von fleischarmer flexitarischer bis hin zu vollständig pflanzenbasierten veganen Ernährungsweisen) entsprechen, sind nach wissenschafltichen Schätzungen gesünder, kostengünstiger und umweltverträglicher als die aktuellen Ernährungsweisen in Deutschland.
- ► Das Ziel, der breiten Bevölkerung gesündere und nachhaltigere Ernährungsmuster zu ermöglichen, erfordert entschlossene und kohärente Strategien in der gesamten Lebensmittelkette, einschließlich:
  - einer Reform der nationalen Ernährungsempfehlungen,
  - der Bereitstellung von Preisanreizen für Verbraucher, die die Umweltauswirkungen von Lebensmitteln berücksichtigen,
  - sowie einer ökologischen Reform der Agrarsubventionen.

1 Options for reducing the environmental impacts and resource demand of the German food system by 2050

1.1 Introduction

This chapter is based on the scientific article “Options for keeping the food system within environmental limits” published in Nature in 2018 by Springmann and colleagues [1]. It adds further information by specifically reporting on the results for Germany.

The global food system is a major driver of climate change [2,3], land-use change and biodiversity loss [4,5], depletion of freshwater resources [6,7], and pollution of aquatic and terrestrial ecosystems through nitrogen and phosphorus runoff from fertilizer and manure application [8–10]. It has contributed to the crossing of several of the proposed planetary boundaries that attempt to define a safe operating space for humanity on a stable Earth system [11–13], in particular those for climate change, biosphere integrity, and biogeochemical flows related to nitrogen and phosphorous cycles. If socio-economic changes towards Western consumption patterns continue, the environmental pressures of the food system are likely to intensify [14–17], and humanity might soon approach the planetary boundaries for global freshwater use, change in land use, and ocean acidification [12,13,18]. Beyond those boundaries, ecosystems could be at risk of being destabilised and losing the regulation functions on which populations depend [12,13].

At the global level, research suggest that a combination of measures will be needed to stay within all planetary boundaries of the food system simultaneously [1]. Without dietary changes towards more plant-based diet, it is unlikely that dangerous levels of climate change can be avoided. Dietary changes are also expected to lead to reduction in the environmental resource use of cropland, freshwater, and fertilizers. Globally, improvements in management practices and technologies in agriculture will be also required to limit pressures on agricultural land, freshwater extraction, and fertilizer use. In addition, halving food loss and waste will be needed for keeping the food system within environmental limits.

The following analysis goes beyond the global results and details the environmental analysis for Germany. I first provide a summary of the research methods we used for the analysis, and then detail the results, including the projections of national food consumption and the associated environmental impacts, followed by the analysis of mitigation options. I’ll end by discussing the implications of the findings. A full description of the analysis can be found in the scientific article “Options for keeping the food system within environmental limits” published in Nature in 2018 by Springmann and colleagues [1].

1.2 Methods

The analysis is based on a global food systems model with country-level detail that resolves the major food-related environmental impacts and includes a comprehensive treatment of measures for reducing these impacts [1]. The model’s regional detail accounts for different production methods and environmental impacts that are linked by imports and exports of primary, intermediate, and final products. We used the food system model and estimates of current and future food demand to quantify food-related environmental impacts at the country and crop-level in 2010, 2030, and 2050 for five environmental domains and the related planetary boundaries: greenhouse-gas (GHG) emission related to climate change, cropland use related to land-system change, freshwater use of surface and groundwater, and nitrogen and phosphorus application related to biogeochemical flows (**Table 1** in the appendix).

To characterise pathways towards a food system with lower environmental impacts that stays within planetary boundaries, we connected a region-specific analysis of the food system to a detailed analysis of measures of change, including reductions in food loss and waste, technological and management-related improvements, and dietary changes towards healthier, more plant-based diets. The scenarios on food loss and waste align with and exceed commitments made as part of the Sustainable Development Goals [19–21]. The scenarios of technological change account for future improvements in agricultural yields, fertilizer application, increases in feed efficiency, and changes in management practices [22–25]. And the scenarios of dietary change include changes towards global dietary guidelines and dietary patterns in line with the current evidence on healthy eating as reviewed by the EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems[26–28].

In our baseline trajectory, we accounted for different socio-economic pathways of population and income growth [24], and projected forward future demand for environmental resources in absence of technological changes and dedicated mitigation measures. Although some of the measures of change considered here can be expected to be implemented by 2050, it is uncertain what level of ambition those will have and implementation will not happen automatically. We therefore analysed each measure of change explicitly and differentiated between two degrees of implementation: medium and high ambition. Measures of medium ambition are in line with stated intentions (e.g. reducing food loss and waste by half), and measures of high ambition go beyond expectations but can be considered attainable with large-scale adoption of existing best practices (e.g. reducing food loss and waste by 75%).

1.3 Environmental impacts of the German food system

We estimated that Germany's food demand in 2010 was responsible for about 62 $MtCO_2eq$ of GHG emissions in the form of methane and nitrous oxide emissions, 90 thousand km^2 of cropland use (grassland was excluded from this analysis), 0.93 km^3 of freshwater resources from surface and groundwater (blue water), and 1.2 TgN of nitrogen application, and 120 GgP of phosphorus application. Environmental analyses can differ depending on the type and scope of greenhouse gases and supply chains that are represented. For example, accounting also for carbon dioxide emissions would further increase the emissions footprint of Germany's food demand [29,30].

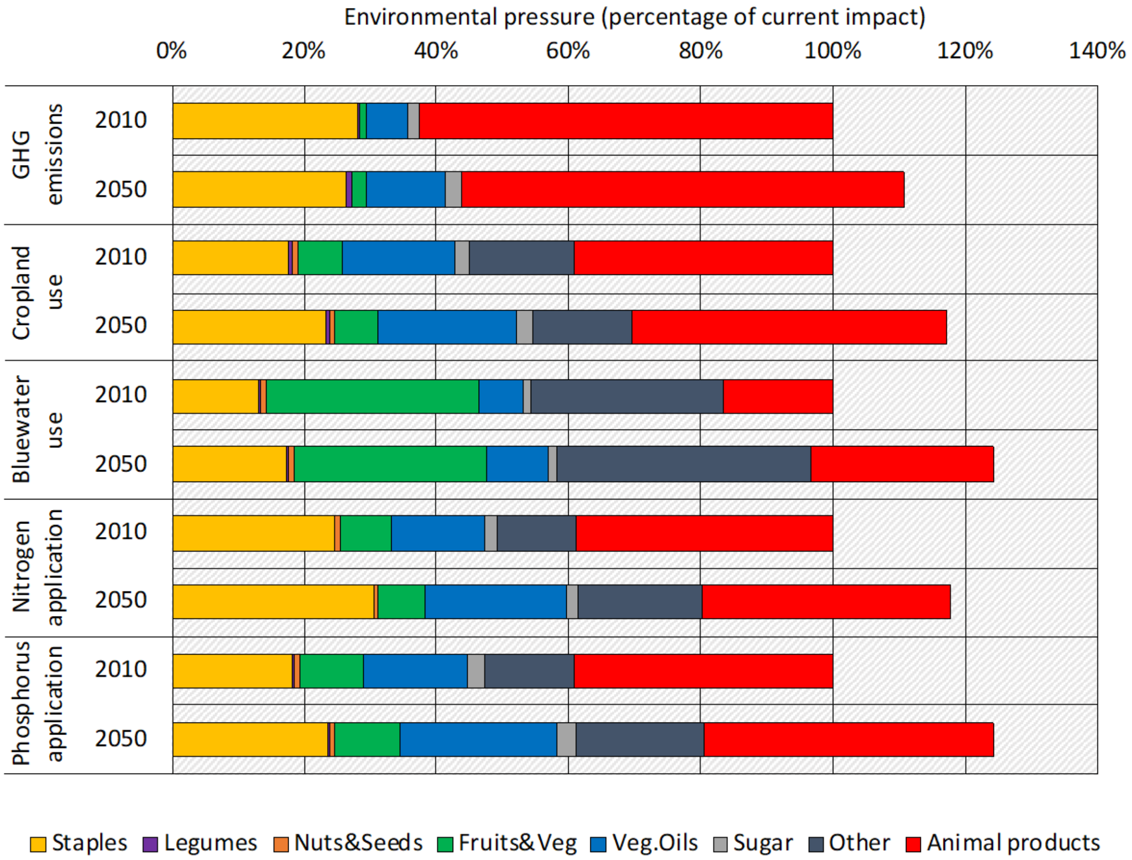
Food production and consumption have been projected to change between 2010 and 2050 as a result of expected socio-economic developments (**Table 2** in the appendix). The German population is projected to decrease by 4% (socio-economic uncertainty: -19% to 0%) and GDP to increase by 61% (25% to 75%) between 2010 and 2050. Driven by changes in per-capita income, the consumption of fruits, vegetables, and legumes is projected to increase by 9-14%, poultry by 11%, sugar and dairy by 5-6%, beef and oil consumption is projected to remain stable (but with a greater proportion of palm oil in the mix of oils), and egg and fish consumption is projected to decrease (-5% and -30%).

As a result of those changes, we project the environmental pressures of the food system to increase by 6-25%, depending on the indicator, and in the absence of technological change and other mitigation measures (**Figure 1**). The greatest increase along this baseline pathway are projected for freshwater use (24%, 23-25 across the different socio-economic projections) and phosphorus application (24%, 22-25), followed by nitrogen application (18%, 17-18), cropland use (17%, 16-18%), and GHG emissions (11%, 6-13).

Specific food groups vary in their environmental impacts (**Figure 1**). In 2050, the production of animal products is projected to generate the majority of food-related GHG emissions (60-63% of total agricultural emissions in 2010; 59-61% in 2050), which is due to their low feed-conversion efficiencies, enteric fermentation in ruminants, and manure-related emissions [31]. In addition, the feed-related impacts of animal products also contribute to pressures on cropland (39-41% of total food-related impacts in 2010; 40-41% in 2050), nitrogen and phosphorus application (each 31-39% in 2010; 32-35% in 2050), and freshwater use (17-22% in 2010; 22-23% in 2050).

Figure 1: Current and projected environmental pressures of the German food demand in 2010 and 2050 on five environmental domains by food group.

Environmental pressures are allocated to the final product, accounting for the use and impacts of primary products in the production of vegetable oils and refined sugar, and for feed requirements in animal products. Impacts are shown as percentage of current impacts for a baseline projection without dedicated mitigation measures for a middle-of-the-road socio-economic development pathway (SSP2).



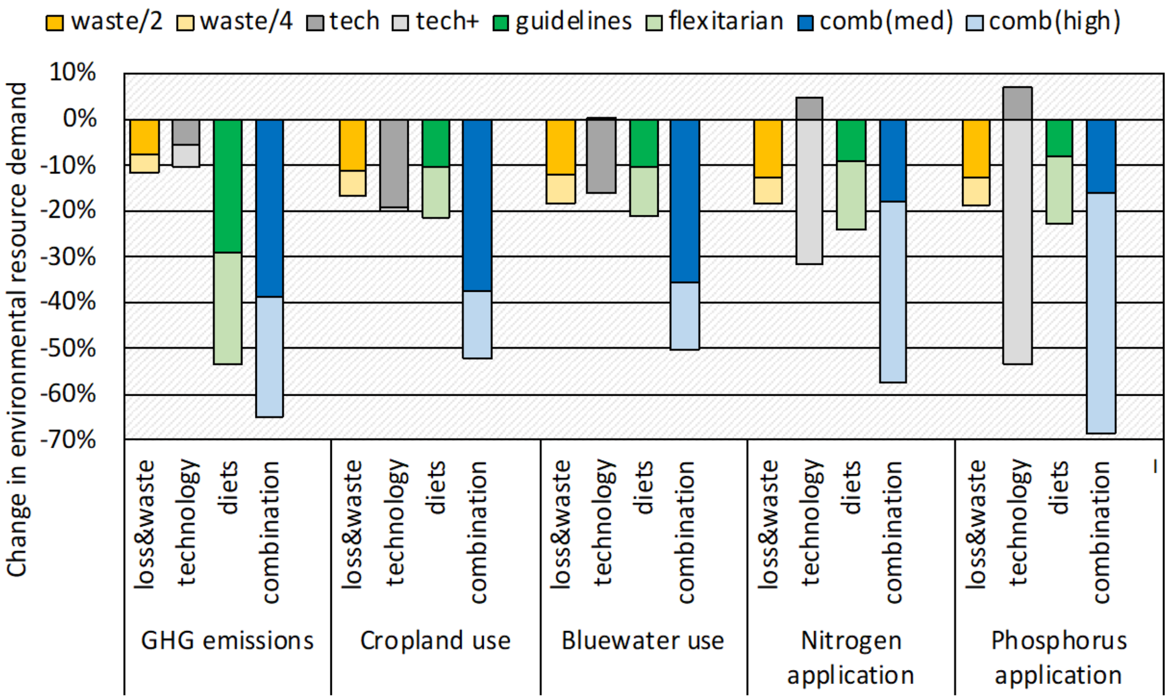
Source: Own illustration based on data from Springmann et al, Nature [1]

1.4 Changes in food management, technology and diets

Reducing food loss and waste is one measure for reducing food demand and the associated environmental impacts. Currently it is estimated that more than a third of all food that is produced is lost before it reaches the market or is wasted by households [19]. For our analysis, we evaluated the impacts of reducing food loss and waste to one half, a value in line with pledges made as part of the Sustainable Development Goals [20], and we also considered a reduction in food loss and waste by 75%, a value likely close to the maximum theoretically avoidable value [21].

We estimate that halving food loss and waste (*waste/2*) would reduce environmental pressures of the German food demand by 8-13% (depending on the environmental indicator) compared to the baseline projection for 2050.Reducing food loss and waste by 75% (*waste/4*) would reduce environmental pressures by 11-19% (**Figure 2**). Relatively more staple crops and fruits and vegetables are wasted than animal products [19], which explains why the impacts of changes in food loss and waste are smaller for the livestock-dominated domains, such as GHG emissions, than for the staple crop-dominated ones, such as cropland and freshwater use, and nitrogen and phosphorus application.

Figure 2: Percentage change in the environmental pollution and resource demand of the German food system in 2050 for changes in diets, technology and management, and food loss and waste for different environmental domains.



Source: Own illustration based on data from Springmann et al, Nature [1]

Technological changes increase the efficiency of production and reduce the environmental impact per unit of food produced. We analysed the most commonly considered technological advances and changes in management practices with respect to their environmental impacts. The measures include increases in agricultural yields which reduce the demand for additional cropland [23,24]; rebalancing of fertilizer application between over and under-applying regions [23] which, together with increasing nitrogen use efficiency [25,32] and recycling of phosphorus [8], reduces demand for additional nitrogen and phosphorus inputs; improvements in water management that increase basin efficiency, storage capacity, and better utilization of rainwater [24]; and agricultural mitigation options, including changes in irrigation, cropping and fertilization that reduce methane and nitrous oxide emissions from rice and other crops, as well as changes in manure management, feed conversion and feed additives that reduce enteric fermentation in livestock [22]. We did not explicitly include pastures in the assessment, but note that changes in the demand for livestock would also be associated with reduced demand for pastures that then could be used for other purposes such as rewilding and afforestation.

We estimate that implementing those measures could reduce the environmental pressures of the German food demand in scenarios of medium ambition (*tech*) by 5-20% (depending on the environmental indicator) compared to the baseline projection for 2050, and by 10-47% in scenarios of high ambition (*tech+*) (**Figure 2**). In each case, the higher-end estimates are for the staple crop-dominated environmental domains (cropland and freshwater use, and nitrogen and phosphorus application) for which general improvements in water management, agricultural yields, phosphorus recycling rates, and nitrogen use efficiencies are particularly effective. The lower-end estimates are for GHG emissions whose large share of livestock-related emissions are, to a large extent, inherent characteristics of the animals and therefore cannot be reduced more substantially with existing mitigation options [22,33].

Dietary changes towards healthier diets can reduce the environmental impacts of the food system when environmentally intensive foods, in particular animal products, are replaced by less intensive food types [16,17]. For our analysis, we analysed dietary changes towards diets in line with global dietary guidelines as proposed by the WHO for the consumption of red meat, sugar, fruits and vegetables, and total energy intake [26,27] *("guidelines");* as well as to more plant-based, so-called flexitarian, diets as proposed as Planetary Heath Diet (PHD) by the EAT-Lancet Commission *("flexitarian")*. The latter includes lower amounts of red and other meats and greater amounts of fruits, vegetables, nuts, and legumes.

We estimate that, compared to the baseline projection for 2050, dietary changes towards healthier diets could reduce GHG emissions and other environmental impacts by 29% and 8-10%, respectively, for the dietary-guidelines scenario, and by 53% and 21-24%, respectively, for the more plant-based diet scenario (**Figure 2**). The changes are in line with the dietary composition of the diets and the environmental footprints of each food group (**Figure 1**). Changes in meat consumption dominate the impacts on GHG emissions, whilst for the other domains the environmental pressures associated with greater consumption of fruits, vegetables, nuts, and legumes are more significant but outweighed by the environmental benefits associated with lower consumption of meat, staple crops, sugar, and a generally lower energy intake in line with healthy bodyweights and recommended levels of physical activity [26].

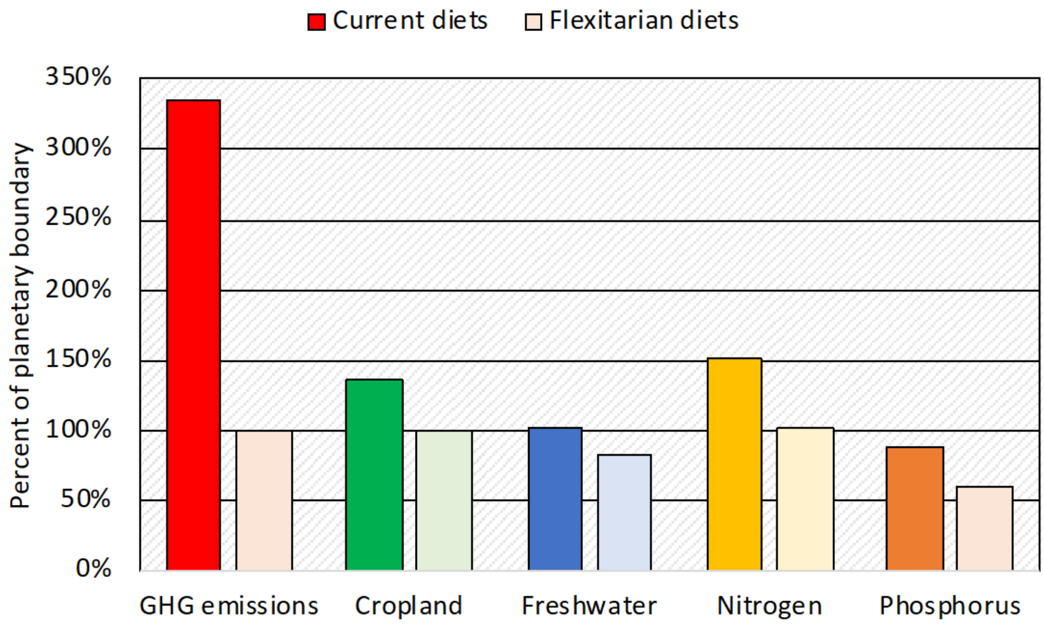
To inform how the combined implementation of some or all of the discussed measures could impact the environmental pressures of the food system, we constructed an environmental option space by combining all measures of medium ambition and all measures of high ambition (**Figure 2**). Combining all measures of medium ambition [*comb(med)*] could reduce environmental pressures by around 15-39% compared to the baseline projection for 2050, whereas combining all measures of high ambition [*comb(high)*] could deliver reductions of 50-69%. In line with the differentiated impacts of the different measures of change, dietary change contributes the most to the reductions in GHG emissions, and technological and management-related changes contribute the most to reductions in the other environmental impacts, whilst reductions in food loss and waste contribute up to a third to the overall reductions.

1.5 Planetary boundaries at the country level

What level of reduction in environmental pressures should be aimed for? Globally, we can explore this question by comparison to the associated planetary boundaries that are intended to describe a safe operating space for humanity. At that level, our analysis suggested that staying within planetary boundaries is possible with a combination of measures of high ambition for GHG emissions and nitrogen and phosphorus application, and with a combination of measures of medium ambition for cropland and freshwater use[1].

Assessing the implications of staying within planetary boundaries is less straight-forward at the country level due to differences in technologies and management practices, levels of food loss and waste, socio-economic conditions, and diets. For example, both agricultural yields and the consumption of environmental intensive foods, such as meat and dairy, are generally higher in high-income countries than in low-income ones, suggesting that high-income countries might require a relatively greater effort in changing diets than technological improvements (whose potential is relatively more exhausted), and vice versa for low-income countries.

Figure 3: Global environmental impacts (as percentage of planetary boundary) for global adoption of the current German diet and a predominantly plant-based flexitarian diets in line with the EAT-Lancet Commission's recommendations.



Source: Own illustration based on data from Springmann et al, The BMJ [34]

To analyse the implications of dietary choices at the country level, we developed a global sustainability test [34]. In that test, we analysed the global environmental impacts if everybody in the world adopted the current diet of one specific country, whilst following their region-specific trajectories of technological and socio-economic progress. A full description of the analysis can be found in the scientific article "The healthiness and sustainability of national and global food based dietary guidelines: Modelling study" published in The BMJ in 2020 by Springmann and colleagues.[34]

For Germany, we found that three out of five planetary boundaries would be transgressed if everybody in the year 2050 ate the current German diet (**Figure 3**). In this estimate, we took into account projections of environmental footprints that included improvements in technologies and management practices (e.g. implementation of agricultural mitigation options and improvements in crop yields, irrigation, and fertilizer application) along a middle-of-the-road socio-economic development pathway. Food-related GHG emissions would be more than three times the level (3.4) that is required to limit global warming to less than 2 degrees Celsius, nitrogen application would be more than 50% greater than a level that would limit aquatic pollution to acceptable levels, and cropland use would be more than a third (37%) above the level that would limit deforestation in line with preserving forest ecosystems and biodiversity.

The global sustainability tests highlight that German dietary choices are not in line with global planetary boundaries, and that ambitious dietary changes are needed to not outsource the responsibility for staying within environmental limits to other countries and sectors.

1.6 Policy implications

Implementation of the food-system measures analysed here depends on the regulatory and incentive framework. Practical options exist in particular for improving technologies and management practices, but adoption of those options might require dedicated investment, the right incentive schemes for farmers, including support mechanisms to adopt best available practices, and better regulation, e.g. of water use and quality. Meaningfully reducing food loss and waste will require measures across the entire food supply chain [21], with possible emphasis on education and awareness campaigns, food labelling, improved packaging that prolongs shelf life, and changes in legislation and business behaviour that promote closed-loop supply chains.

For dietary change, the available evidence suggests that providing information without additional economic or environmental changes has a limited influence on behaviour, and that integrated, multicomponent approaches that include clear policy measures might be best suited for changing diets [35,36]. Those can include a combination of media and education campaigns; labelling and consumer information; fiscal measures, such as taxation, subsidies, and other economic incentives; school and workplace approaches; local environmental changes; and direct restriction and mandates [36]. An important first step would be to align national food-based dietary guidelines with the current evidence on the environmental impacts of diets [37,38]. The next chapter discusses dietary change in more detail.

2 Environmental implications of changing Germany's current eating patterns

2.1 Introduction

This chapter is based on the scientific article "The healthiness and sustainability of national and global food based dietary guidelines: Modelling study" published in The BMJ in 2020 by Springmann and colleagues [34]. It adds further information by specifically reporting on the results for Germany.

The food we eat have a significant impact on our health. Currently, imbalanced diets low in fruits, vegetables, nuts and whole grains, and high in red and processed meat are responsible for the greatest health burden globally and in most regions [39]. In addition to imbalanced diets, about 2 billion people are overweight and obese, and 2 billion have nutritional deficiencies, whilst about 800 million are still suffering from hunger due to poverty and poorly developed food systems [40]. As the dietary transition towards more processed and high-value products continues in many regions of the world, these dietary health risks are expected to worsen [3]. The concept of sustainable diets combines the twin challenges of creating a food system that supplies healthy diets for a growing population, whilst reducing its environmental impacts and staying within planetary boundaries [10,11].

In the following, I report on the national-level, environmental results of an integrated nutritional-health-environmental analysis of dietary-change options [34]. The analysis considers a greater range of dietary-change scenarios as the last chapter, including a larger variety of specialised dietary patterns that are in line with the current evidence on healthy eating as reviewed by the EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems, as well as a dedicated analysis of Germany's national dietary guidelines. In the following, I describe the research methods my colleagues and I used and then lay out the country-level results of our analysis for Germany. A full description of the analysis can be found in the scientific article "The healthiness and sustainability of national and global food based dietary guidelines: Modelling study" published in The BMJ in 2020 by Springmann and colleagues [34].

2.2 Methods

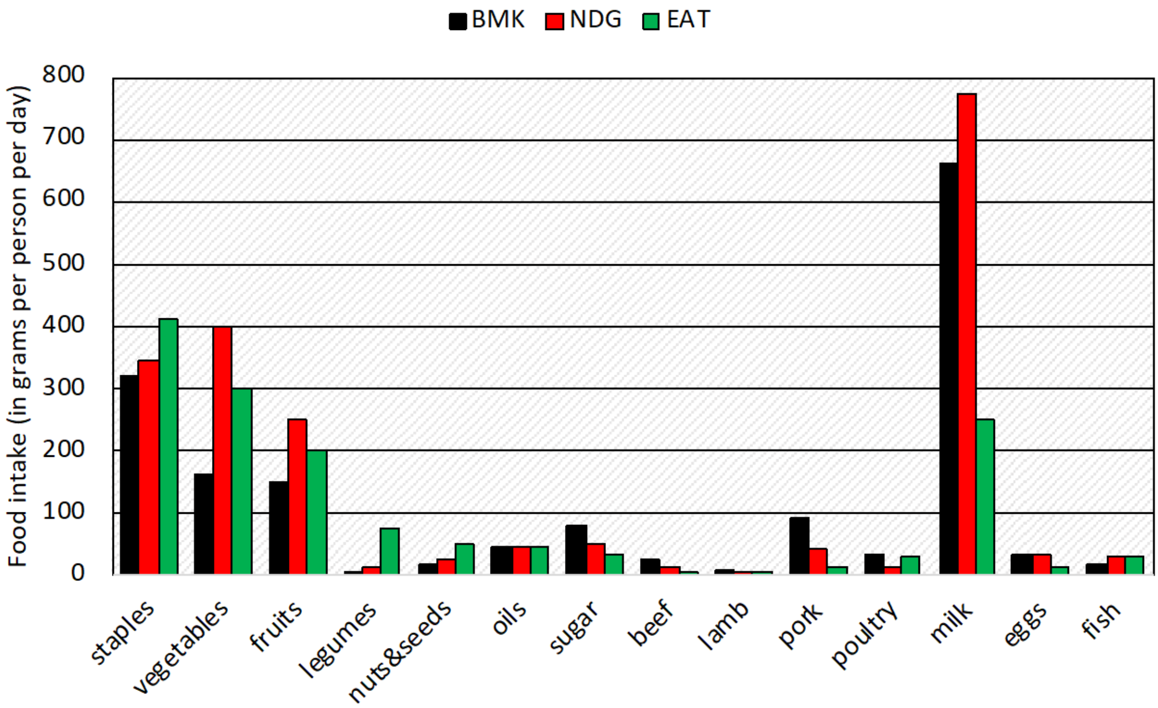
Diet scenarios

We constructed four nutritionally balanced dietary patterns that are in line with the current evidence on healthy eating [44]. The dietary patterns include energy-balanced varieties of flexitarian, pescatarian, vegetarian, and vegan dietary patterns in line with the recommendations of the EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems. The flexitarian dietary patterns contain no processed meat, low amounts of red meat (including beef, lamb, pork) and sugar, moderate amounts of poultry, dairy and fish, and generous amounts of fruits, vegetables, legumes, and nuts. The other three dietary patterns replace either meat (pescatarian, vegetarian) or all animal source foods (vegan) to one third by fruits and vegetables and to two thirds by either fish and seafood (pescatarian diets) or legumes (vegetarian and vegan diets). We regionalised the dietary patterns by preserving the current national preferences for types of grains, fruits, red meat and fish.

For comparison, we constructed a dietary representation of the German food-based dietary guidelines issued by the German Nutrition Society (DGE). For that purpose, we extracted verbatim key messages from the DGE nutrition circle, in particular from the notes about exemplary quantities that accompanies the circle (**Table 3** in the appendix). We followed a standardised coding method for translating the key messages into a quantitative representation, and applied those to baseline consumption and weight data [34]. Compared to the EAT-Lancet recommendations (**Table 4** in the appendix), the DGE recommends similar amounts of fruits and vegetables (five portions or more), but greater amounts of dairy (one glass of milk and 50-60g of cheese that in milk equivalents sum to three times the EAT-Lancet recommendations of not more than one glass of milk per day) and red meat (300-600g per week of meat in total whose mean value, given national preferences for different types of meat, equate to almost four times the EAT-Lancet recommendation of one serving per week or less) (**Figure 4**, see also **Table 5** in the appendix).

As consumption data, we used globally comparable estimates of the amount of food that is available for consumption in a country, provided by the FAO, and adjusted those for food wasted during consumption [45,46]. An alternative would have been to rely on dietary surveys [47,48]. However, underreporting is a persistent problem in dietary survey [49,50], and regional differences in survey methods would have meant that our results would not be comparable between countries.

Figure 4: Food intake (in grams per person per day) as recommended by the DGE (NDG), the EAT-Lancet Commission (EAT), in comparison to current intake (BMK).



Source: Own illustration based on data from Springmann et al, The BMJ [34]

Environmental analysis

For analysing the environmental implications of dietary changes, we used country and crop-specific environmental footprints for GHG emissions, cropland use, freshwater use, and nitrogen and phosphorus application [1]. The footprints are based on global datasets on environmental resource use in the producing region [51–54], and they have been adjusted for the proportion of food, and the associated footprint, that is imported, exported, and processed to reflect the resource demand of consuming a specific food in a specific country [1,55].

We also analysed whether the dietary changes were in line with global environmental targets by modelling their universal adoption across all countries. The rationale of this global sustainability test, as noted in the previous chapter, was to assess whether global targets can be met without imposing exceptions for one country or group of countries. The targets included were the Paris Agreement to limit global warming to below 2 degrees Celsius, the Aichi Biodiversity Target of limiting the rate of land-use change, as well as the Sustainable Development Goals and planetary boundaries related to freshwater use, and nitrogen and phosphorus pollution (**Table 1**). For deriving the target values, we isolated the diet-related portion of the different environmental targets [1].

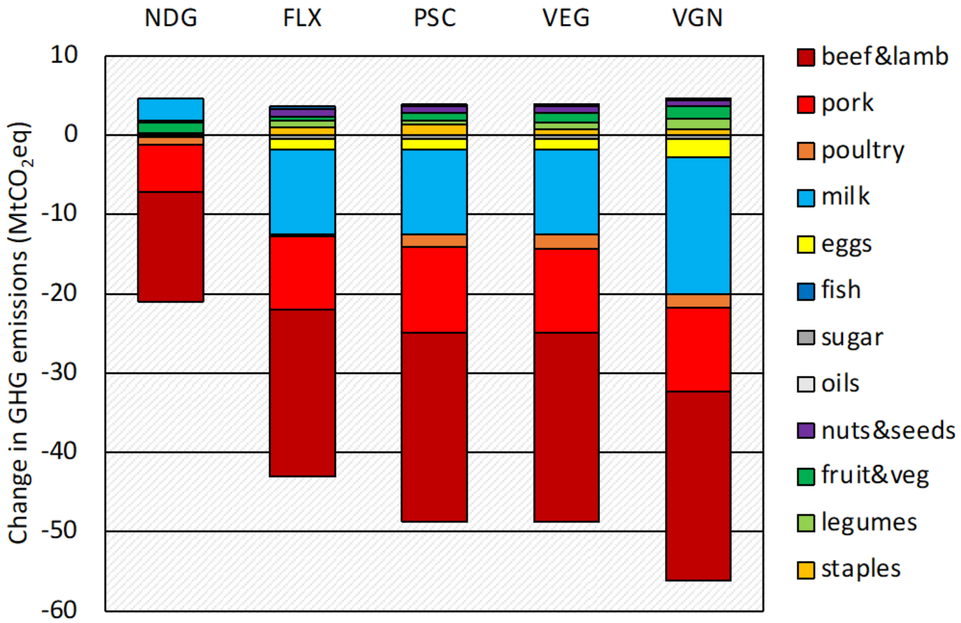
2.3 Results

The environmental analysis underlines the large potential for diet-related reductions in environmental pollution (**Figure 5**). Dietary changes from current diets to the predominantly plant-based dietary patterns were associated with a reduction in the food-related GHG emissions of Germany of 40-52 MtCO_2eq, which represent a reduction of 63-81% in overall food-related GHG emissions, with greater values for the more plant-based dietary patterns. By food group, the majority of reductions were due to lower consumption of beef (up to 37%), dairy (up to 27%), and pork (up to 17%). In comparison, the DGE recommendations were associated with a reduction in food-related GHG emissions of 26%, in particular due to higher recommended intake of dairy and less stringent recommendations on meat consumption.

Dietary changes also impacted environmental resource use. The use of cropland, nitrogen and phosphorus were reduced by 16-34% for dietary changes to the different dietary patterns, with greatest reduction for the more plant-based patterns. However, without improvements in water management techniques the use of freshwater increased by up to 46% due to increased consumption of fruits and vegetables. In comparison, dietary changes to the DGE recommendations were associated with a 34% increase in water use and a 2-7% reduction in other environmental resource use. Changes in freshwater use depends more strongly on technological improvements and changes in management,[9] which suggests that a synergistic perspective on sustainable diets should include both technological and dietary aspects.

The global sustainability test detailed in the last chapter takes into account context-specific improvements in technology and management practices, as well as with reductions in food loss and waste. In that test (**Figure 6**), the global environmental impacts of the DGE recommendations led to some improvements compared to current diets, but they were still incompatible with the environmental limits related to climate change, cropland use, freshwater use, and nitrogen application. In contrast, all more plant-based dietary patterns stayed within environmental limits, including those related to freshwater use, when paired with concomitant food-system changes.

Figure 5: Change in food-related GHG emissions in Germany by food group and diet scenario.



Source: Own illustration based on data from Springmann et al, The BMJ [34]

2.4 Implications

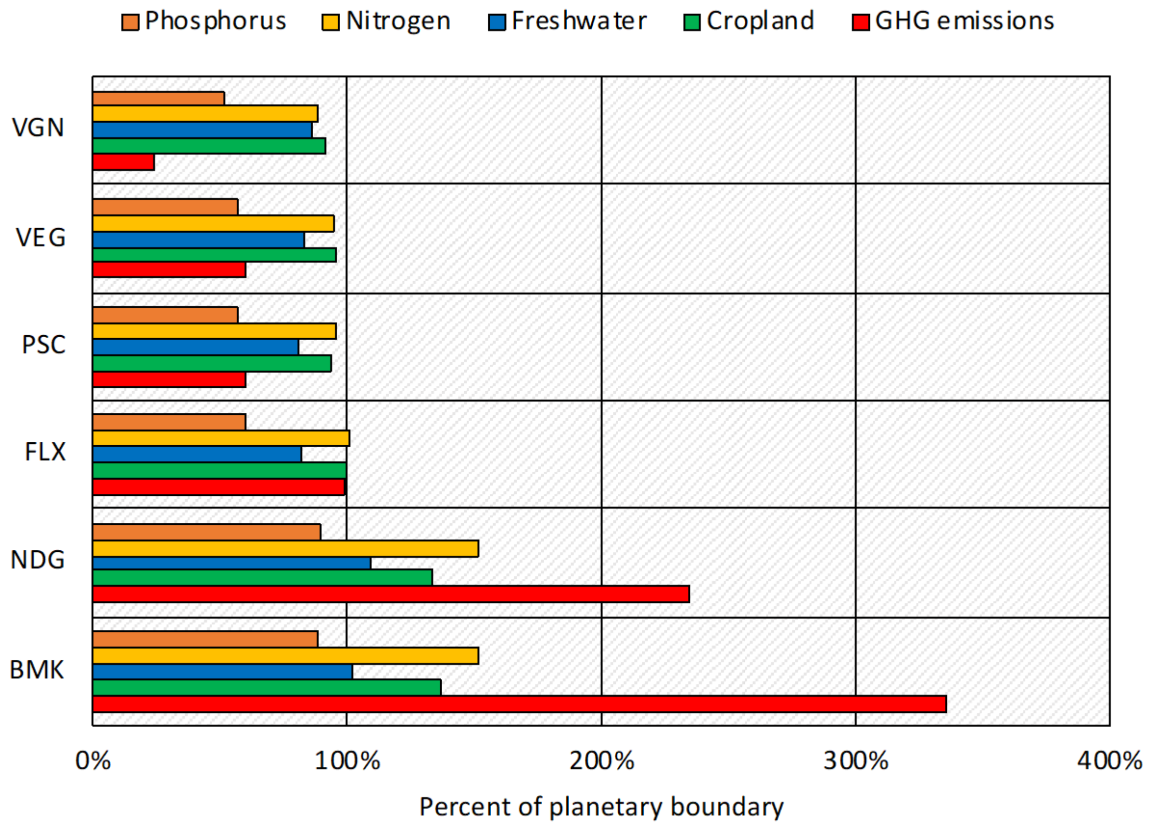
Addressing dietary composition and energy intake as part of food-based dietary guidelines (FBDG) could be a comprehensive strategy for achieving sustainable diets. Whether food-based dietary guidelines should include sustainability criteria has been a major issue of discussion in several countries [13,36]. Here we find that food-based dietary recommendations that reflect the current evidence on healthy eating, including balanced energy intake, low amounts of red meat and sugar, low to moderate amounts of other animal source foods, and generous amounts of fruits, vegetables, legumes and nuts, can result in diets which would be in line with key sustainable development goals.

To be in line with such recommentdations and to be environmentally sustainable (and healthy), the German diet would have to become significantly more plant-based. Compared to a dietary pattern that is healthy and environmentally sustainable at a global level, such as the Planetary Health Diet developed by the EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems, the German diet contains more than eight times too much red meat (including beef, lamb, and pork), almost three times too much dairy and sugar, as well as 38% too few fruits and vegetables, 30% too few whole grains, 67% too few nuts, and 95% too few legumes (**Table 5** in the appendix). To adopt a healthy and sustainable diet, red meat consumption would have to be reduced by 88%, and dairy consumption by 62%, whilst fruit and vegetable consumption would have to increase by 62%.

Developing FBDGs that are healthy and sustainable are an important starting point for encouraging the uptake of healthy and sustainable diets at a population level. However, most countries, including Germany, exhibit poor uptake of FBDGs [34]. For FBDGs to have a greater impact on diets, they require clear and consistent policy support. Policy measures that could incentivise a greater uptake of FBDGs include investment in targeted health promotion programmes, adopting public procurement standards that are in line with FBDGs, and making sure policies from other governmental departments and ministries are aligned and not contradicting the recommendations of FBDGs, e.g. when it comes to national and supranational agricultural strategies and policies, public-private partnerships, and regulation of the food sector. The next chapter discusses the food-system regulation and the economic aspects of dietary changes in more detail.

Figure 6: Global environmental impacts (as percentage of planetary boundary) for global adoption of the current German diet (BMK), the German national dietary guidelines (NDG), as well as predominantly plant-based dietary patterns, including flexitarian (FLX), pescatarian (PSC), vegetarian (VEG), and vegan (VGN) diets.

Impacts are specified for the year 2050 in line with the specification of the environmental targets. To isolate the impacts of dietary change, each diet scenario (including BMK) includes technological improvements along a business-as-usual scenario and a halving of food loss and waste.



Source: Own illustration based on data from Springmann et al, The BMJ [34]

3 Cost implications of dietary change in Germany

3.1 Introduction

This chapter is based on the scientific article "The global and regional costs of healthy and sustainable dietary patterns: a modelling study" published in Lancet Global Health in 2021 by Springmann and colleagues [60]. It adds further information by specifically reporting on the results for Germany.

As the previous two chapters have shown, our diets are not sustainable. Whilst the importance and benefits of dietary changes towards healthy and sustainable diets are increasingly recognised [16,59], much less is known about the economic dimensions of such changes, including the affordability and costs of diets. Indeed, the adoption of sustainable could be hampered if such diets proved to be more expensive and unaffordable for some populations. In this chapter I provide estimates of the costs of sustainable diet patterns based on current market prices [60]. In addition, I estimate the climate-change costs related to diets that are currently not included in market prices.

The environmental consequences of our dietary choices impose costs on society –the costs of climate damages is but one example – that are currently not reflected in the price of those foods or diets that contribute to these detrimental impacts.[16] Economists call such instances – where private actions impose costs on society – negative externalities which lead to market failures and overconsumption and production of, in this case, unsustainable foods and diets [61]. According to economic theory, correcting such market failures involves integrating the previously unaccounted costs in the price of goods, so that consumers and producers can make their production and consumption decision based on the full costs.

In this chapter, I focus on the costs of different dietary patterns based on the costs of ingredients obtained from national markets, as well as the climate-change costs that are associated with these dietary choices but are not currently reflected in the cost of diets. It should be noted that, in addition to climate change, there are additional externalities of food production such as pollution of groundwater, soil degradation or eutrophication, which are not considered here [62]. A full description of the analysis can be found in the scientific article "The global and regional costs of healthy and sustainable dietary patterns: a modelling study" published in Lancet Global Health in 2021 by Springmann and colleagues [60].

3.2 Methods

Colleagues and I calculated the costs of diets by pairing estimates of food demand for different consumption patterns with estimates of commodity prices in different years and under considerations of food-system and socio-economic changes [60]. The price data were based on a detailed list of commodity prices collected by statistical offices for the year 2017 as part of the International Comparison Program (ICP) led by the World Bank [63]. To estimate current food consumption, we used globally comparable estimates of the amount of food that is available for consumption in a country, provided by the Food and Agriculture Organization of the United Nations, and we adjusted those for food wasted during consumption using region and commodity-specific estimates [45,64].

In line with the sustainable-diet literature [55,58,59,65,66], we differentiated between four nutritionally balanced (i.e., fulfilling nutrient requirements) and predominantly plant-based dietary patterns, including flexitarian, pescatarian (with increased seafood demand to be met by sustainable aquaculture), as well as vegetarian and vegan diets. The flexitarian diet was adopted from the EAT-Lancet Commission on Healthy Dies from Sustainable Food Systems [59] and the more specialised dietary patterns were constructed by replacing the amount of animal products in the flexitarian diets.

Because the exact composition of those diets is variable, we constructed two variants of each pattern, in which animal products were replaced by a mix of fish (pescatarian) or legumes (vegetarian, vegan) and either fruits and vegetables (high-veg variant) or whole grains (high-grain variant). The two variants of each specialised dietary pattern are meant to capture the diversity of such patterns and highlight particular trade-offs that are relevant for affordability as whole grains are usually cheaper per calorie than fruits and vegetables. The high-grain variants contained the same amount of fruits and vegetables as the flexitarian diets, and 2-9% more grains (by weight) than the high-veg variants (which still is about a third less than current diets).

To analyse the implications that different socio-economic development trajectories could have for the relative differences in the cost of diets, we used price and demand projections from the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) [51], a global partial equilibrium multi-market model of agricultural production, demand, trade, and prices. Because we were interested in the costs of diets, and not only of final consumption, we added the commodity and region-specific estimates of food wasted at home to the estimates of food intake in each scenario [45], including the baseline estimates.

For the valuation of the diet-related costs of climate change, we first calculated diet-related GHG emissions by pairing the estimates of food demand in the different diet scenarios with footprints of GHG emissions from life-cycle assessments that were differentiated by commodity and region and accounted for future improvements in management and technology [67,68]. We then paired those with estimates of the social cost of carbon (SCC) which represents the economic cost caused by an additional ton of GHG emissions [69]. Compared to the SCC values suggested by the German Federal Environment Agency [70], our values are similar for the year 2030 (185 vs 215 EUR/tCO_2-eq), lower in the base year (115 vs 195 EUR/tCO_2-eq), and higher in 2050 (492 vs 250 EUR/tCO_2-eq) due differences in the integrated assessment models used in the calculation and the associated emissions trajectory.

3.3 Results

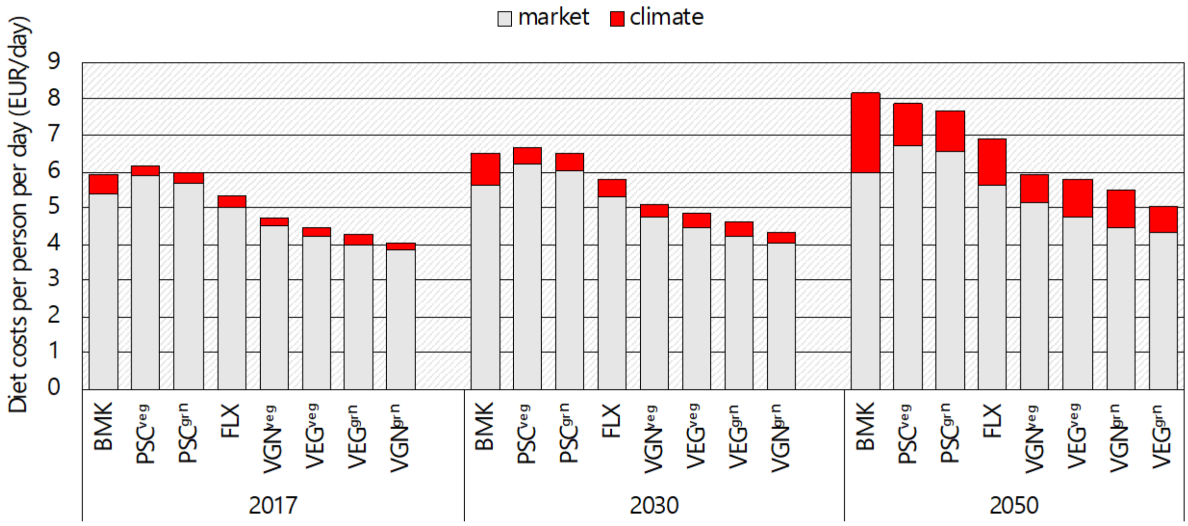
According to our estimates, the average cost of diets in Germany in 2017, including food wasted by households, was EUR 5.4 per person per day (**Figure 7**). The more plant-based dietary patterns were more affordable in comparison. The cost savings ranged from 6% for flexitarian diets, over 21-25% for vegetarian diets, to 15-28% for vegan diets. In contrast, pescatarian diets were 8-11% more expensive than current diets.

The external costs of Germany diets are substantial. The social costs of climate change associated with the food-related GHG emissions of Germany diets amounted to EUR 17 billion per year in 2017, increasing more than threefold (in line with increasing damage costs) to EUR 63 billion per year in 2050. In comparison to the daily cost of diets, these costs represented 10% of the market costs of diets in 2010, 15% in 2030, and 37% in 2050 (**Figure 7**).

The cost advantage of the more plant-based dietary patterns increased when considering the climate-change costs of diets. The more plant-based dietary patterns were associated with substantially lower GHG emissions, which resulted in 43-67% lower climate change costs than current diets. The total cost savings of the more plant-based dietary patterns ranged from 9-32% in 2017 to 10-33% in 2030, and to 15-38% in 2050, in each case with the greatest cost advantage for variants of vegan diets (**Figure 7**).

Figure 7: Cost of diet in Germany by diet scenario, cost component, and year.

The dietary patterns include current diets (benchmark, BMK), as well as high-veg and high-grain variants of pescatarian (PSC), vegetarian (VEG), and vegan (VGN) diets. In these variants, animal products were replaced by a mix of fish (pescatarian) or legumes (vegetarian, vegan) and either fruits and vegetables (high-veg variant "veg") or whole grains (high-grain variant "grn").



Source: Own illustration based on data from Springmann et al, Lancet Planetary Health [60]

3.4 Implications

Our findings have several policy implications. The findings suggest that dietary-change interventions that incentivise adoption of more plant-based dietary patters that, in modelled studies [1,55], have been assessed as healthier and more sustainable than current diets, can help consumers in Germany reduce costs whilst, at the same time, contribute to fulfilling national climate-change commitments. Some fiscal measures intended to incentivise dietary changes, such as environmentally motivated taxes [71,72], have been portrayed as being potentially financially regressive for households. Our findings suggest that need not be the case, and that progressive policy approaches can, when successful in changing diets, be financially progressive as well, and particularly so when they contribute to internalising some of the costs that are currently not accounted for. The next chapter discusses these policy approaches in more detail.

4 Economic incentives for dietary change in Germany – environmentally motivated taxes

4.1 Introduction

This chapter is based on the scientific article "Mitigation potential and global health impacts from emissions pricing of food commodities" published in Nature Climate Change in 2017 by Springmann and colleagues [71]. It adds further information by specifically reporting on the results for Germany.

The global food system is responsible for more than a quarter of all greenhouse gas (GHG) emissions, most of which are related to livestock [3,73,74]. In 2050, food-related GHG emissions could take up half of the total emissions allowed to keep global warming below 2 degrees Celsius [16], and exceed this figure by 2070 [75]. To avoid dangerous levels of climate change, reducing the GHG emissions related to food production will have to become a critical component of policies aimed at mitigating climate change [76,77]. Despite that, agriculture has long been excluded from comprehensive climate policies, something motivated by difficulties in monitoring agricultural emissions [78–80], the lack of technical mitigation options [81,82], and concerns about the potential impacts on food security [83,84], among others.

Pricing GHG emissions at source, as is usually envisaged for climate policies covering the energy sector, incentivises emissions reductions across the life cycle, but would require detailed farm-level measurements, for example of methane emissions from enteric fermentation in the digestive tract of ruminants [78], and of nitrous oxide emissions from agricultural soils treated with nitrogen fertilizers [79,80]. Such non-point sources of emissions are highly variable and therefore very costly to monitor [81]. And although some technological mitigation options exist [82], most of the agricultural GHG emissions are related to intrinsic characteristics of the agricultural system (such as methane emissions from ruminants and nitrous oxide emissions from fertilizers) and therefore difficult to address without substantial effects on agricultural output and the availability of food [83,84].

Demand-side policies could be a viable option for addressing the environmental costs associated with food production. Levying GHG taxes on the consumption side instead of the production side has been argued to be an economically preferable approach, given the nature of agriculture described above [85,86]. In addition, measures to change diets away from emissions-intensive food commodities, such as meat and dairy, towards more plant-based diets are seen to offer great potential for reducing GHG emissions [16,17,75,76,87–89], and could be associated with additional co-benefits in terms of improvements in human health [16,17], something policy-makers are increasingly becoming aware of [38,90]. Here I report on an analysis of the impacts that levying GHG taxes on food commodities in Germany could have on GHG emissions. A full description of the analysis can be found in the scientific article "Mitigation potential and global health impacts from emissions pricing of food commodities" published in Nature Climate Change in 2017 by Springmann and colleagues [71].

4.2 Methods

My colleagues and I used an agriculture-economic model, the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), to project future food consumption for 62 agricultural commodities in over 150 world regions [24]. Our analysis focusses on the year 2020 and accounts for price-mediated changes in the consumption of particular commodities, as well as the effects of price changes on substitution across food groups (e.g., replacing beef consumption with poultry). It also takes into account the impacts that tax-related changes in income have on consumption. We assumed taxes are implemented independently in each country (i.e. the result for each country show the impact if the carbon pricing was implemented in that country only), and that production in each country adjusts to internal changes in demand. As our focus is on the demand side we did not explicitly track the induced changes in world prices, trade, or agricultural production in other countries.

We used a database of life-cycle analyses to quantify the emissions related to food production [17,31], and to calculate GHG taxes on food commodities corresponding to their emissions intensities, differentiated by region and food group, and an emissions price based on estimates of the social cost of carbon which corresponds to calculating the net present value of future climate damages associated with one additional tonne of carbon dioxide equivalent (tCO_2-eq) [91]. In our main analysis, we adopted an emissions price of EUR 125 tCO_2-eq^{-1} (US dollars per metric tonne of CO_2 equivalents) which is in line with prices needed to constrain future temperature rise in line with stated policy goals [69]. GHG taxes, which differed by region and food group, were levied as consumption taxes in each region and therefore covered both imported food commodities and domestically produced commodities that were not exported.

We begin our analysis by estimating the impacts of levying weighted GHG taxes on all food commodities. Motivated by concerns for food and nutrition security, in particular for low-income households, we then exempt health-critical food groups, such as fruits and vegetables and staple crops, from taxation, and we explore tax scenarios focused on animal-based foods, red meat, and beef. In addition, we considered scenario variants in which income losses due to GHG taxes were compensated by other fiscal interventions, e.g. by recycling the revenues back to the consumer directly or by increasing public expenditure; and scenario variants in which three quarters of the GHG tax revenues in each region were used for subsidising fruit and vegetable consumption by lowering commodity prices. The latter scenarios would leave a portion of revenues available for other uses, e.g. for general government spending or saving, and to meet any administrative costs that could be associated with levying GHG taxes on food commodities.

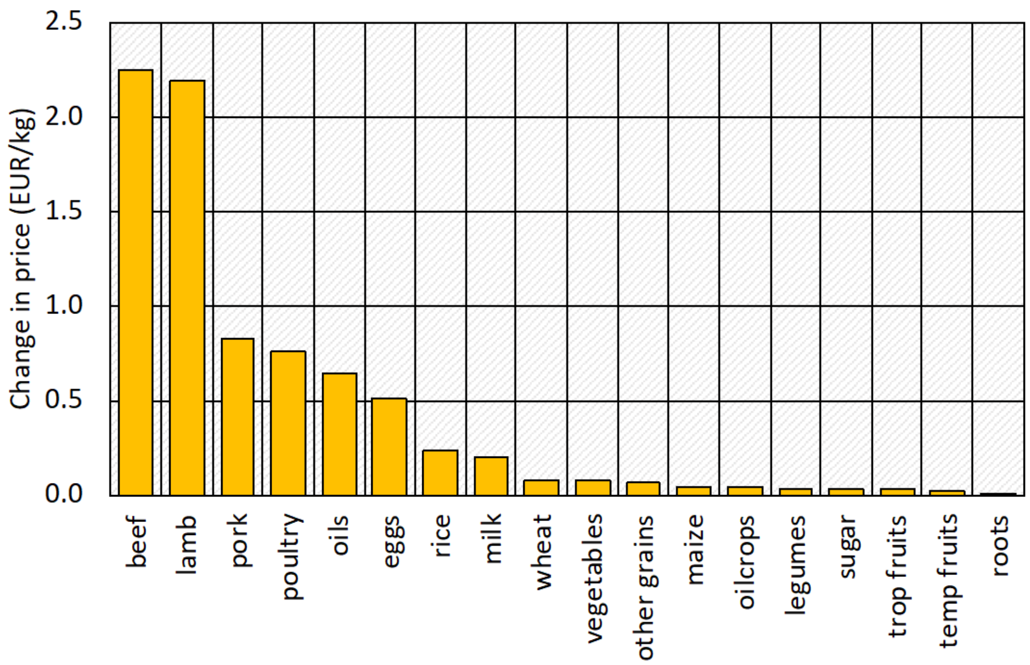
4.3 Results

With a GHG emissions price of EUR 125 tCO_2-eq^{-1}, GHG taxes on food commodities were highest for animal-sourced foods, such as beef and lamb (EUR 2.2 kg^{-1} each), and pork and poultry (EUR 0.8 kg^{-1} each), and low for plant-based foods (< EUR 0.2 kg^{-1}) (**Figure 8**). The relative increases in commodity prices were 58% for beef, and 24-43% for other animal source foods, including 39% for poultry, 36% for milk products, 32% for pork, and 24% for eggs. Increasing the price of foods by those amounts resulted in significant reduction in red meat of one and a quarter portions (124 g) per person per week in Germany (-11%), a reduction in milk intake of one portion a week (209 g, -5%), and in overall emissions reductions of 10 $MtCO_2$-eq (-9%).

When a portion of the tax revenues were used for subsidizing fruit and vegetable consumption (e.g. via health promotion programmes), the effective price of fruits and vegetables was reduced by 33-53%, which increased consumption by one portion per person per day (84 g, 27%), without significantly affecting the changes in GHG emissions (-8.4 $MtCO_2$-eq compared to -10.3 $MtCO_2$-eq).

Taxing schemes that reduced the tax base (e.g. to beef only) reduced both the health and emissions benefits, and schemes in which the revenues were used for income compensation had similar impacts as the full tax scheme, but without the added benefits of the coupled subsidy scheme that were associated with increased fruit and vegetable consumption.

Figure 8: Climate change costs of food-related emissions by food group for Germany in 2020.



Source: Own illustration based Springmann et al, Nature Climate Change [71]

4.4 Implications

Our analysis suggests that levying GHG taxes on food commodities could be a health-promoting climate-change mitigation policy in Germany. Compensating income losses associated with tax-related price increases, or preferably using a portion of tax revenues for health promotion are policy options that could help avert any negative impacts for exposed populations, whilst promoting changes towards diets which are more environmentally sustainable. Although the dietary changes incentivised by taxing the GHG emissions of foods identified in this study are substantial, additional policy measures will be needed for fully achieving healthy and sustainable dietary patterns at a population level [92].

5 Economic incentives for food-system change in Germany – reform of agricultural subsidies

5.1 Introduction

This chapter is based on the scientific article "Options for reforming agricultural subsidies from health, climate, and economic perspectives" published in Nature Communications in 2022 by Springmann and Freund [98]. It adds further information by specifically reporting on the results for Germany.

Model-based analyses suggest that in addition to technological innovation and changes in farming practices, also large-scale dietary changes and concomitant changes in agricultural production will be needed to achieve healthy diets for a growing population, whilst staying within the environmental limits of the food systems [1]. For example, instead of additional global increases in the production of staple crops, animal-source foods, and sugar crops – estimated at 40-80% between 2010 and 2050 – a food system underpinning healthy and sustainable diets would require shifts from those food groups to foods that are both healthy and lower in environmental resource use and pollution, such as fruits, vegetables, legumes, nuts and seeds.

Reforming agricultural subsidies could play a role in supporting shifts towards healthier and more sustainable food systems. Agricultural subsidies are an important factor for influencing production. In 2016, they represented 25% of the value of production in OECD countries, and 15% in non-OECD countries [93]. Although subsidies have become increasingly decoupled, commodity-specific support measures, either through direct coupling or through market-price support still represent a significant portion of agricultural subsidies, and decoupled payments have often supported the continuation of once coupled production systems. The importance of aligning agricultural subsidies with a comprehensive set of societal goals that include both health and the environment is increasingly recognised [94–97], but quantitative analyses that adopt a comprehensive food-systems perspective that goes beyond tracking changes in production are largely lacking.

Here I report on an analysis of options for reforming agricultural susbsidies from health, environmental, and economic perspectives [98], focusing in particular on the last two aspects. Agricultural subsidies are decided on not at a German national level, but at the EU level (albeit with input from Germany policymakers). I will therefore summarise the results of the study that were obtained for the EU. The results can inform the stance German policymakers and the public towards ecological subsidy reform. A full description of the analysis can be found in the scientific article "Options for reforming agricultural subsidies from health, climate, and economic perspectives" published in Nature Communications in 2022 by Springmann and Freund [98].

5.2 Methods

My colleague and I used an economic-environment-health modelling framework to analyse the impacts of agricultural subsidy reform [98]. For this, we combined a detailed economic representation of agricultural subsidies [99] with region and commodity-specific environmental footprints [1], and with a health assessment of the burden of diet-related diseases that are associated with dietary risk factors, such as low intake of fruits and vegetables, and high intake of red meat [34]. In our environmental analysis, we focus on changes in agricultural greenhouse gas emissions (specifically methane and nitrous oxide) because greenhouse gas emissions, compared to other environmental impacts, are less modifiable by farm-level management and more by changes in the mix of production [1]. Within the framework, we account for the dynamic interactions that e.g. how price and supply-demand reactions influence production, consumption, trade, and the distribution of environmental impacts.

We used the modelling framework to analyse various options for reforming agricultural subsidies in line with health and climate-change objectives. The options we considered ranged from a complete removal of subsidies; over partial and complete conditioning of subsidies to food commodities with beneficial environmental and health characteristics; to structural changes in the global subsidy scheme that, in addition to changes in the conditioning of subsidies, included a more equal provision of subsidies across countries. For the conditioning of subsidies, we adopted a food-group approach and, in line with projections of the required food-system transformation for healthy and sustainable diets, redirected different proportions of subsidies to the production of horticultural commodities (fruits, vegetables, legumes, nuts) that have been associated with beneficial health and environmental characteristics.

Our food-group focus on horticultural products can be seen as analogous to approaches that aim to condition subsidies explicitly to the actual health and environmental characteristics of food commodities. Life-cycle analyses indicate that the impacts of what type of food is grown far outweighs how it is grown, especially when comparing animal source foods with plant-based ones, and when comparing different foods within the same region [100,101]. Similarly, epidemiological studies indicate that non-starchy plant-based foods such as fruits, vegetables, legumes, and nuts are associated with reduced risks for various diet-related diseases, while other foods are either associated with increased risk (red and processed meat) or are seen as relatively risk neutral (poultry and dairy) compared to baseline diets [59,102]. Here we focus on these general characteristics of horticultural foods, noting that additional differentiation might sometimes be appropriate.

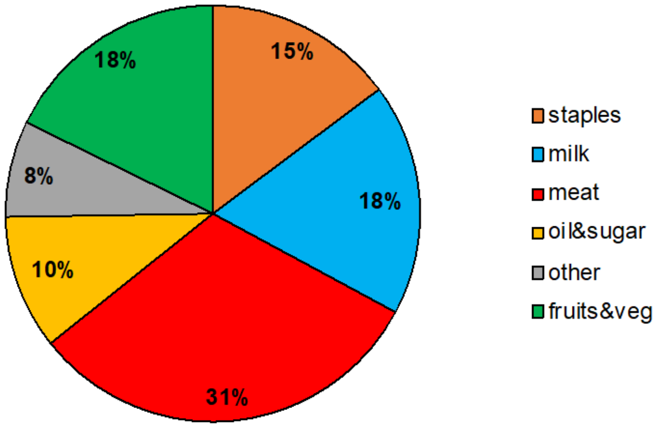
5.3 Results

Agricultural support measures in the EU, excluding those related to border policies and tariffs, totalled USD 74 billion in 2017. Ninety percent of those are not coupled to any specific commodity or group of commodities, and 60% are categorised as transfers to producers that do not require production. However, analysing how subsidies are used in practice provides a different picture (**Figure 9**): by final use, about half of transfer payments are used to produce meat (31%) or milk (18%), followed by horticultural products (18%), staple crops (15%), and oils and sugar (10%).

Conditioning all agricultural subsidies to the production of healthy and sustainable foods (here taken to be fruits, vegetables, legumes, and nuts) increased their production by about 40%. At the same time, the production of meat and milk was reduced by 5% and 3% respectively. Associated with those changes in production were reductions in food-related greenhouse gas emissions of 4%, driven primarily by the reduction in the production of livestock products. The changes in production also had an impact on relative prices and on consumption. The intake of fruits and vegetables increased by about 20% or one serving a day (100g), and that of meat and dairy by a third to a half of a portion per week each (-3%, -2%). Conditioning half of the subsidies to the production of healthy and sustainable foods resulted in about half the impacts on production, environmental impacts, and consumption.

Removing all subsidies resulted in reductions in production for all food commodities. This produced similar reductions in greenhouse gas emissions, but did had no added benefit of increasing the consumption of fruits and vegetables. Instead, the intake of fruits and vegetables decreased in this scenario, which can be expected to have detrimental impacts for dietary risk and population health.

Figure 9: Distribution of agricultural subsidies in the EU in 2017.



Source: Own illustration based Springmann et al, Nature Communications [98]

5.4 Implications

Agricultural subsidies are an important factor influencing production choices. Our analysis suggests that agricultural subsidy reform in the EU could make a meaningful contribution to a transition towards healthier and more sustainable food systems, including reductions in environmental pollution and improvements in population health. However, trade-offs exist between the different reform options. Removing agricultural subsidies could be environmentally beneficial, but it could negatively impact population health. In contrast, redirecting subsidies to the production of foods with beneficial health and environmental characteristics could reduce GHG emissions and improve population health.

An open question is how to balance gains in one sector (e.g. horticulture) with losses in another (e.g. livestock). In principle, making subsidies conditional to the production of healthy and sustainable food commodities provides both an incentive and support for farmers to transition between sectors. In addition, our analysis showed that economic losses at a national level can be mitigated by combining a coupling of agricultural subsidies with a reduction in the overall amount of subsidies, e.g. as part of a global restructuring of subsidies [98]. Together, these results highlight that a health and environmentally sensitive subsidy reform is possible without reductions in economic welfare.

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A Appendix

Table 1: Planetary boundaries of the food system.

The references in the table refer to the original article (see source).

Planetary boundary	Motivation	Method	Boundary
Climate change	Further increasing GHG emissions increase climate-related risks to ecosystems and cultures, e.g. from sea-level rise and increased occurrence of extreme weather events, such as heat waves, extreme precipitation, and coastal flooding [82].	Food-related GHG emissions in line with limiting global warming to below 2 degrees Celsius [63] with uncertainty derived from a model comparison of integrated assessment models [58].	A budget of 4.7 (4.3-5.3) GtCO2-eq of food-related GHG emissions, including methane and nitrous oxide, but excluding carbon dioxide in line with IPCC methodology.
Land-system change	Further increasing the amount of agricultural land through deforestation could impact the functioning of ecosystems [3], release large amounts of carbon dioxide 1, and diminish habitat for wild species and thereby pose major threats to biodiversity [4].	Analysis of conservation levels for each forest biome in line with preserving ecosystem integrity, scaled up to a global value [12] and related to cropland use [33,39].	Not increasing pressures on forests by keeping global cropland use at 12.6 (10.6-14.6) Mkm2. Converting productive grazing land into cropland can relax the boundary value.
Freshwater use	Further depletion and overexploitation of groundwater resources impairs natural streamflow, wetlands and related ecosystems, and can lead to land subsidence and salt-water intrusion in deltaic areas [6] and, eventually, to cascading impacts on the global hydrological cycle [77].	Basin-level assessments of the environmental flow requirements of river systems [12,20] scaled to agricultural bluewater use [5,33].	Maintaining environmental flow requirements by limiting agricultural bluewater use to 1,980 (780-3,190) km3 or below.
Bio-geochemical flows of nitrogen and phosphorus	Agricultural runoff from overapplication of fertilizers leads to eutrophication, an increase in chemical nutrients in the water [7,9], which in turn can lead to excessive blooms of algae that deplete underwater oxygen levels resulting in so-called dead zones in coastal oceans [8].	Analysis of eutrophication risk based on nitrogen and phosphorus pollution estimates of agricultural runoff and ecological thresholds [19], with an upper value in line with re-balancing of application between over and under-applying regions [32].	Limiting nitrogen and phosphorus application from fertilizers to 69 (52-113) TgN and 16 (8-17) TgP respectively.

Source: Adapted from Springmann et al, Nature [1]

Table 2: Overview of income and population changes for different socio-economic development pathways.

The pathways include a middle-of-the-road development pathway (shared socio-economicpathway 2, SSP2), a more optimistic pathway with higher income and lower population growth (SSP1), and a more pessimistic pathway with lower income and greater population growth (SSP3).

	Population (million)			**GDP (USD billion)**	
	2010	2030	2050	2010	2030
Global					
SSP1	6,879	8,016	8,479	67,559	153,527
SSP2	6,879	8,280	9,187	67,559	143,136
SSP3	6,879	8,521	9,975	67,559	134,108
HIC					
SSP1	1,087	1,218	1,316	36,248	57,323
SSP2	1,087	1,209	1,289	36,248	55,201
SSP3	1,087	1,141	1,099	36,248	51,455
UMC					
SSP1	932	1,029	1,039	10,587	22,563
SSP2	932	1,060	1,120	10,587	21,542
SSP3	932	1,096	1,229	10,587	20,757
LMC					
SSP1	3,906	4,486	4,630	20,125	70,388
SSP2	3,906	4,651	5,062	20,125	63,563
SSP3	3,906	4,837	5,640	20,125	59,275
LIC					
SSP1	996	1,333	1,549	1,395	4,926
SSP2	996	1,411	1,776	1,395	4,469
SSP3	996	1,501	2,072	1,395	4,202
DEU					
SSP1	82	83	82	2,727	3,608
SSP2	82	81	79	2,727	3,488
SSP3	82	77	67	2,727	3,258

Source: Own illustration based on data from Springmann et al, Nature [1]

Table 3: Key messages associated with the DGE Nutrition Circle.

Lebensmittel	Orientierungswerte für Erwachsene
Gruppe 1: Getreide, Getreideprodukte, Kartoffeln	täglich • 4 - 6 Scheiben (200 - 300 g) Brot **oder** 3 - 5 Scheiben (150 - 250 g) Brot und 50 - 60 g Getreideflocken und • 1 Portion (200 - 250 g) Kartoffeln (gegart) **oder** 1 Portion (200 - 250 g) Nudeln (gegart) **oder** 1 Portion (150 - 180 g) Reis (gegart) Wählen Sie Vollkornprodukte.
Gruppe 2: Gemüse und Salat	täglich • mindestens 3 Portionen (400 g) Gemüse 300 g gegartes Gemüse und 100 g Rohkost / Salat **oder** 200 g gegartes Gemüse und 200 g Rohkost / Salat Essen Sie sowohl gegartes als auch rohes Gemüse und Salat.
Gruppe 3: Obst	täglich • mindestens 2 Portionen (250 g) Obst Essen Sie Obst, wenn möglich mit Schale und frisch. 25 g Nüsse können 1 Portion Obst ersetzten.
Gruppe 4: Milch und Milchprodukte	täglich • 200 – 250 g Milch und Milchprodukte und • 2 Scheiben (50 – 60 g) Käse Wenn Sie Kalorien sparen wollen, wählen Sie die fettarmen Varianten.
Gruppe 5: Fleisch, Wurst, Fisch und Eier	wöchentlich • 300 – 600 g fettarmes Fleisch und fettarme Wurst und • 1 Portion (80 – 150 g) Seefisch (wie Kabeljau oder Rotbarsch) und • 1 Portion (70 g) fettreichen Seefisch (wie Lachs, Makrele oder Hering) und • bis zu 3 Eier
Gruppe 6: Öle und Fette	täglich • 10 – 15 g Öl (z. B. Raps-, Walnuss- oder Sojaöl) und • 15 – 30 g Margarine oder Butter Bevorzugen Sie die pflanzlichen Öle und Fette.
Gruppe 7: Getränke	täglich • rund 1,5 Liter Bevorzugen Sie kalorienfreie/-arme Getränke.

Source: Adapted from the DGE (https://www.dge.de/ernaehrungspraxis/vollwertige-ernaehrung/ernaehrungskreis/, accessed 1 September 2020)

Table 4: Food-based dietary recommendations for a Planetary Health Diet developed by the EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems.

	Macronutrient intake grams per day (possible range)	Caloric intake kcal per day
Whole grains		
Rice, wheat, corn and other	**232**	**811**
Tubers or starchy vegetables		
Potatoes and cassava	**50** (0–100)	**39**
Vegetables		
All vegetables	**300** (200–600)	**78**
Fruits		
All fruits	**200** (100–300)	**126**
Dairy foods		
Whole milk or equivalents	**250** (0–500)	**153**
Protein sources		
Beef, lamb and pork	**14** (0–28)	**30**
Chicken and other poultry	**29** (0–58)	**62**
Eggs	**13** (0–25)	**19**
Fish	**28** (0–100)	**40**
Legumes	**75** (0–100)	**284**
Nuts	**50** (0–75)	**291**
Added fats		
Unsaturated oils	**40** (20–80)	**354**
Saturated oils	**11.8** (0-11.8)	**96**
Added sugars		
All sugars	**31** (0–31)	**120**

Source: Adapted from the EAT-Lancet Report [59]

Table 5: Food intake (grams per day per person) in the different diet scenarios, including baseline diets (BMK), national dietary guidelines (NDG), WHO recommendations (WHO), the EAT-Lancet Commission in Healthy Diets from Sustainable Food Systems, including flexitarian (EAT), pescatarian (PSC), vegetarian (VEG), and vegan (VGN) diets.

As consumption data, we used globally comparable estimates of the amount of food that is available for consumption in Germany, provided by the FAO, and adjusted for food waste during consumption.[45,46]

Food groups	Diet scenarios						
	BMK	NDG	WHO	EAT	PSC	VEG	VGN
staples	317	343	400	412	414	381	390
> whole grains	162	146	114	232	232	217	221
fruit&veg	309	650	400	500	600	700	800
> vegetables	162	400	209	300	380	450	500
> fruits	148	250	191	200	220	250	300
legumes	4	12	4	75	75	100	125
nuts&seeds	16	25	16	50	50	50	50
oils	46	46	46	47	47	47	47
sugar	78	50	50	31	31	31	31
meat	150	64	123	43			
> red meat	119	51	92	14			
> unprcocessed red meat	80	34	80	14			
> processed meat	39	17	12				
> beef	23	10	18	3			
> lamb	5	2	4	1			
> pork	90	39	70	11			
> poultry	31	13	31	29			
milk	662	775	662	250	250	250	
eggs	31	31	31	13	13	13	
fish	18	26	18	28	56		

Source: Own illustration based on data from Springmann et al, The BMJ [34]