Analysis and valuation of the health and climate change cobenefits of dietary change

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What we eat greatly influences our personal health and the environment we all share. Recent analyses have highlighted the likely dual health and environmental benefits of reducing the fraction of animal-sourced foods in our diets. Here, we couple for the first time, to our knowledge, a region-specific global health model based on dietary and weight-related risk factors with emissions accounting and economic valuation modules to quantify the linked health and environmental consequences of dietary changes. We find that the impacts of dietary changes toward less meat and more plant-based diets vary greatly among regions. The largest absolute environmental and health benefits result from diet shifts in developing countries whereas Western high-income and middle-income countries gain most in per capita terms. Transitioning toward more plant-based diets that are in line with standard dietary guidelines could reduce global mortality by 6–10% and food-related greenhouse gas emissions by 29–70% compared with a reference scenario in 2050. We find that the monetized value of the improvements in health would be comparable with, or exceed, the value of the environmental benefits although the exact valuation method used considerably affects the estimated amounts. Overall, we estimate the economic benefits of improving diets to be $1–31 trillion US dollars, which is equivalent to 0.4–13% of global gross domestic product (GDP) in 2050. However, significant changes in the global food system would be necessary for regional diets to match the dietary patterns studied here.

The choices we make about the food we eat affect our health and have major ramifications for the state of the environment. The food system is responsible for more than a quarter of all greenhouse gas (GHG) emissions (1), of which up to 80% are associated with livestock production (2, 3). The aggregate dietary decisions we make thus have a large influence on climate change. High consumption of red and processed meat and low consumption of fruits and vegetables are important diet-related risk factors contributing to substantial early mortality in most regions while over a billion people are overweight or obese (4). Without targeted dietary changes, the situation is expected to worsen as a growing and more wealthy global population adopts diets resulting in more GHG emissions (5) and that increase the health burden from chronic, noncommunicable diseases (NCDs) associated with high body weight and unhealthy diets (6).

Recent analyses have highlighted the environmental benefits of reducing the fraction of animal-sourced foods in our diets and have also suggested that such dietary changes could lead to improved health (7–14). They have shown that reductions in meat consumption and other dietary changes would ease pressure on land use (11, 12) and reduce GHG emissions (7, 11–14). Changing diets may be more effective than technological mitigation options for avoiding climate change (14) and may be essential to avoid negative environmental impacts such as major agricultural expansion (7) and global warming of more than 2 °C (13) while ensuring access to safe and affordable food for an increasing global population (8, 15).

The diets investigated in these studies include diets with a prorata reduction in animal products (ruminant meat, total meat, dairy) (11, 13, 14), specific dietary patterns that include reduced or no meat (such as Mediterranean, “pescatarian,” and vegetarian diets) (11, 12), and diets based on recommendations about healthy eating (7, 11). The health consequences of adopting these diets have not been explicitly modeled or quantitatively analyzed, but instead inferences have been drawn from information available in the epidemiological literature (16). In the most comprehensive study to date, Tilman and Clark (12) analyzed the GHG emissions of a series of diets that differed in their animal-sourced food content and presented their results alongside a series of observational studies of the health consequences of adopting the different diets. Here, we use a region-specific global health model to link the health and environmental consequences of changing diets. We also make a first attempt, to our knowledge, to estimate the economic value of different dietary choices through their effects on health and the environment. For the health analysis, we built a comparative assessment model to estimate age and region-specific mortality associated with changes in dietary and weight-related risk factors (4, 17). The specific risk factors influence mortality through dose–response relationships, which allow us to compare different dietary scenarios based on their exposure to those risk factors. Given the availability of consistent epidemiological data, we focused on changes in the consumption of red meat, and of fruits and vegetables, which together accounted for more than half of diet-related deaths in 2010 (4), and also on the fraction of people who are overweight or obese through excess calorie consumption, which too is associated strongly with chronic disease mortality (18, 19).

The food system is responsible for more than a quarter of all greenhouse gas emissions while unhealthy diets and high body weight are among the greatest contributors to premature mortality. Our study provides a comparative analysis of the health and climate change benefits of global dietary changes for all major world regions. We project that health and climate change benefits will both be greater the lower the fraction of animal-sourced foods in our diets. Three quarters of all benefits occur in developing countries although the per capita impacts of dietary change would be greatest in developed countries. The monetized value of health improvements could be comparable with, and possibly larger than, the environmental benefits of the avoided damages from climate change.

Significance

The food system is responsible for more than a quarter of all greenhouse gas emissions while unhealthy diets and high body weight are among the greatest contributors to premature mortality. Our study provides a comparative analysis of the health and climate change benefits of global dietary changes for all major world regions. We project that health and climate change benefits will both be greater the lower the fraction of animal-sourced foods in our diets. Three quarters of all benefits occur in developing countries although the per capita impacts of dietary change would be greatest in developed countries. The monetized value of health improvements could be comparable with, and possibly larger than, the environmental benefits of the avoided damages from climate change.

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Data deposition: The region-specific results of the health, environmental, and economic valuation analyses have been deposited in the Oxford University Research Archive (ORA), ora.ox.ac.uk/ (doi: 10.5287/bodleian:XObxm2eb0).

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The disease states included were coronary heart disease (CHD), stroke, type 2 diabetes (T2DM), and cancer that is an aggregate of site-specific cancers. These four disease states accounted for about 60% of NCD deaths and for about 40% of deaths globally in 2010 (6). Given that dietary and weight-related risk factors are predominantly associated with chronic disease mortality, we focused on the health implications of changes in those risk factors for adults (aged 20 y and older).

For the environmental analysis, we linked regional and scenario-specific food type consumption levels to GHG emissions using Tilman and Clark’s metaanalysis of life cycle studies (12) although we adjusted for likely future productivity improvements (3). In the economic analysis, we placed a monetary value on changes in GHG emissions by using estimates of the social cost of carbon (20) and explored monetizing the health consequences using the value of statistical life (21, 22) and projections of health-care expenditure by cause of death (23–25). We stress from the outset that we consider the economic valuation to be a first step and that the estimates are not exactly comparable nor do they include all consequences of dietary changes.

We used this coupled modeling framework to analyze the environmental and health impacts of four dietary scenarios in the year 2050 (SI Appendix, Table S1) (7, 9–13). The first (referred to below as REF) is a reference scenario based on projections from the Food and Agriculture Organization of the United Nations (FAO), with adjustments to take into account the fraction of nonedible and wasted food (26, 27). The second scenario [healthy global diets (HGD)] assumes the implementation of global dietary guidelines on healthy eating (16, 28) and that people consume just enough calories to maintain a healthy body weight (29). The last two scenarios also assume a healthy energy intake but based on observed vegetarian diets (30, 31), either including eggs and dairy [lacto-ovo vegetarian (VGT)] or completely plant-based [vegan (VGN)]. The three nonreference scenarios are not intended to be realizable dietary outcomes on a global level but are designed to explore the range of possible environmental and health outcomes of progressively excluding more animal-sourced foods from human diets (7, 9–13).

The different diet scenarios were implemented by adjusting the region-specific diets described in the REF scenario, which maintained the regional character of food consumption (SI Appendix, section S1). The HGD diet included (per day) a minimum of five portions of fruits and vegetables (16), fewer than 50 g of sugar (16), a maximum of 43 g of red meat (28), and an energy content of 2,200–2,300 kcal, depending on the age and sex composition of the population (29). The VGT and VGN diets differed from the HGD in including six (VGT) or seven (VGN) portions of fruits and vegetables (30, 31) and one portion of pulses (30, 31), with no red meat, poultry, or fish, and in the VGT diet no dairy or eggs. Energy intake was adjusted to the target levels by varying the proportion of staple portions of fruits and vegetables (16), fewer than 50 g of sugar (16), and 2,300 kcal, depending on the age and sex composition of the population (29). The VGT and VGN diets differed from the HGD in including six (VGT) or seven (VGN) portions of fruits and vegetables (30, 31) and one portion of pulses (30, 31), with no red meat, poultry, or fish, and in the VGT diet no dairy or eggs. Energy intake was adjusted to the target levels by varying the proportion of staple foods in the diet, but preserving their region-specific composition.

Results

Less than half of all regions meet, or are projected to meet, dietary recommendations for the consumption of fruit, vegetables, and red meat, and also exceed the optimal total energy intake (SI Appendix, Fig. S1). As a consequence, large changes in the food system would be necessary to achieve the dietary patterns considered here (SI Appendix, Table S7). In the HGD scenario, the changes include increasing global fruit and vegetable consumption by 25% (99 g d⁻¹) and by more in Sub-Saharan Africa (190%, 323 g d⁻¹), South Asia (101%, 248 g d⁻¹), and Latin America (39%, 138 g d⁻¹) and decreasing global red meat consumption by 56% (42 g d⁻¹) and by more in Western high-income and middle-income countries (78%, 113 g d⁻¹) and 69%, 72 g d⁻¹, respectively), East Asia (74%, 93 g d⁻¹), and Latin America (72%, 83 g d⁻¹). The nonmeat diets require greater increases in the consumption of fruits and vegetables (VGT, 39%, 152 g d⁻¹; VEG, 54%, 212 g d⁻¹), and of pulses (324%, 61 g d⁻¹, each). Compared with the reference scenario, the alternative diets require 15% less total energy intake.

Health Impacts. Moving to diets with fewer animal-sourced foods would have major health benefits (Fig. L4). Compared with the reference scenario, we project that adoption of global dietary guidelines (HGD) would result in 5.1 million avoided deaths per year [95% confidence interval (CI), 4.8–5.5 million] and 79 million years of life saved (CI, 75–83 million) (Fig. L4 and SI Appendix, Fig. S2). The equivalent figures for the vegetarian (VGT) diet are 7.3 million avoided deaths (CI, 7.0–7.6 million) and 114 million life years saved (CI, 111–118 million) and for the vegan (VGN) diet 8.1 million avoided deaths (CI, 7.8–8.5 million) and 129 million life years saved (CI, 125–133 million). Differentiated by risk factor, more than half of avoided deaths (51–57% across the three scenarios) were due to decreased red meat consumption, 24–35% to increased fruit and vegetable consumption, and 19–30% to a lower prevalence of being overweight and obese associated with limiting excessive energy intake. The reduced mortality in the VGT and VGN scenarios compared with the HGD scenario was due to lower red meat consumption (1.7 million additional avoided deaths in each) and higher fruit and vegetable consumption (VGT, 0.8 million; VGN, 1.8 million additional avoided deaths). Across the three nonreference scenarios, about 45–47% of all avoided deaths were from reduced coronary heart disease (CHD), 26% from stroke, 16–18% from cancer, and 10–12% from type 2 diabetes mellitus (T2DM) (SI Appendix, Fig. S3). Adopting the reference diet reference scenario, the impact of each diet was 1.0 per year from CHD, stroke, cancer, and T2DM in 2050 by 12% (HGD), 17% (VGT), and 19% (VGN) and the overall number of deaths from all causes by 6% (HGD), 9% (VGT), and 10% (VGN) (SI Appendix, Table S8).

Our analysis allows a regional breakdown of the health benefits of dietary change. The greatest number of avoided deaths (~72% across the three nonreference scenarios) occurred in developing countries, in particular in East Asia (31–35%) and South Asia (15–19%) (Fig. L4). Reducing red meat consumption was the risk factor that had the most positive effect on health in East Asia (78–82%), Western high- and middle-income countries (64–71%; 58–65%), and Latin America (42–48%). Increasing fruit and vegetable consumption was responsible for the majority of avoided deaths in the least developed regions (South Asia, 75–83%; Sub-Saharan Africa, 72–84%). Reduced energy intake and the consequent fewer people overweight and obese were particularly important in the Eastern Mediterranean (41–79%), Latin America (32–48%), and Western high- and middle-income countries (29–40%; 20–33%). The model results can also be expressed as per capita reductions in red meat (6.1 ± 0.1 GtCO₂, 97%) whereas reductions in red meat consumption (VGT, 0.8 million; VGN, 1.8 million additional avoided deaths) in each) and higher fruit and vegetable consumption (VGT, 0.8 million; VGN, 1.8 million additional avoided deaths). Across the three nonreference scenarios, about 45–47% of all avoided deaths were from reduced coronary heart disease (CHD), 26% from stroke, 16–18% from cancer, and 10–12% from type 2 diabetes melilitus (T2DM) (SI Appendix, Fig. S3). Adopting the reference diet reference scenario, the impact of each diet was 1.0 per year from CHD, stroke, cancer, and T2DM in 2050 by 12% (HGD), 17% (VGT), and 19% (VGN) and the overall number of deaths from all causes by 6% (HGD), 9% (VGT), and 10% (VGN) (SI Appendix, Table S8).

Emissions Impacts. In line with other studies (7, 12, 13), we find that dietary changes toward less animal-sourced foods can help mitigate an expected growth in food-related GHG emissions. Under our reference scenario, we project GHG emissions associated with food consumption to increase by 51%, from 7.6 ± 0.1 gigatons CO₂-eq y⁻¹ (measured in CO₂ equivalents) in 2005/2007 to 11.4 ± 0.2 GtCO₂-eq y⁻¹ in 2050 (SI Appendix, Fig. S8). Food-related GHG emissions in the HGD scenario were 8.1 ± 0.1 Gt CO₂-eq y⁻¹, which is 29% less than REF emissions in 2050 and 7% greater than emissions in 2005/2007. The two vegetarian diets resulted in food-related GHG emissions at midcentury (VGT, 4.2 ± 0.1 Gt CO₂-eq y⁻¹; VEG, 3.4 ± 0.1 Gt CO₂-eq y⁻¹) that were 45–55% lower than the 2005/2007 levels and 63–70% lower than REF emissions. Emissions reductions in the HGD scenario were largely attributable to reduced red meat consumption (3.2 ± 0.1 GtCO₂-eq y⁻¹) whereas reductions in red meat (6.1 GtCO₂-eq y⁻¹) and poultry (1.08 ± 0.01 GtCO₂-eq y⁻¹) were responsible for lower VGT emissions, and lower consumption of red meat (76%), poultry (13%), and eggs and dairy (1.2 ± 0.03 GtCO₂-eq y⁻¹) for lower VGN emissions (Fig. 1B). In relation to an emissions pathway that is believed to be likely to limit global temperature...
increase to below 2 °C (32), we project that the ratio of food-related GHG emissions to GHG emissions from all sources increases from 16% in 2005/2007 to 52%, 37%, 19%, and 15% in 2050 in the REF, HGD, VGT, and VGN scenarios, respectively (SI Appendix, Fig. S6 and section S13).

We can identify where changes to region-specific diets contribute the most to reduced GHG emissions. About three-quarters of the total reductions (72–76%) across the nonreference scenarios occurred in developing countries, in particular in East Asia (HGD, 55%; VGT, 41%; VEG, 38%) and Latin America (13–15%) (Fig. 1B). In contrast, food-related GHG emissions per capita fell twice as much in developed compared with developing countries across all three nonreference scenarios (SI Appendix, Fig. S10), driven mainly by reductions in red meat consumption (SI Appendix, Table S7). As a result, the difference in food-related per capita GHG emissions between developed and developing countries narrowed (SI Appendix, Fig. S9). The average per capita GHG emissions from someone in a developing country was 53% that of a person from a developed country in the REF scenario but only 26% and 20% in the HGD and VGT scenarios, respectively. In the VGN scenario, food-related GHG emissions per capita were 4% lower in developing countries than in developing ones, which was due to higher fruit and vegetable consumption in some developing countries (exceeding adjusted values in the baseline) (SI Appendix, Table S8). On a country level, 77 out of the 105 regions in the environmental analysis reduced their food-related GHG emissions per capita in the HGD scenario whereas an increase occurred in 28 (SI Appendix, Fig. S11). These increases in emissions were relatively minor (together they made up about 2% of the total changes in food-related GHG emissions) and were primarily due to increasing energy intake in regions with extensive current undernourishment, in particular in Africa. In the VGT and VGN scenarios, the number of regions where per capita food-related GHG emissions increased was reduced from 28 to 1 (the Democratic Republic of the Congo).

Economic Value. We used two complementary approaches to assess the economic value of the health benefits associated with dietary change. First, using "cost-of-illness" techniques (23, 25), we calculated the direct health-care costs and the indirect costs of informal care and lost work days that are associated with deaths from specific diseases. Second, we used region-specific data on the willingness of individuals to pay for incremental deaths from specific diseases. We estimated the monetized value of statistical life (VSL) (21, 22), to obtain an estimate of the cost of the lives (and life-years) saved under each dietary scenario. The two approaches span the range of potential valuation methods (33, 34); the VSL approach is commonly used in cost-benefit analysis (22) to indicate societal preferences whereas the cost-of-illness approach, in particular its direct cost component, highlights the economic impact on the health-care sector and on patients (23, 25).

To explore the economic benefits of reduced GHG emissions, we used estimates of the social cost of carbon (20) for the year 2050 and calculated the value of avoided harm due to less CO₂ in the atmosphere (Fig. 2). We found that adoption of diets meeting dietary guidelines (HGD) would have monetized...
environmental benefits of $234 billion·y⁻¹, with values in the range $89–729 billion·y⁻¹ for different assumptions about discount rates (Method). The benefits were greater for diets with fewer animal-sourced foods: for VGT, $511 billion·y⁻¹ ($194–1,589 billion·y⁻¹) and, for VGN, $570 billion·y⁻¹ ($217–1,773 billion·y⁻¹). As a percentage of expected world GDP in 2050, the benefits amounted to 0.10% (0.04–0.32%) for HGD diets, 0.22% (0.08–0.69%) for VGT diets, and 0.25% (0.09–0.77%) for VGN diets. The regional distribution of the monetized environmental benefits largely reflects the changes in GHG emissions (SI Appendix, Fig. S14 and Fig. 1B).

Discussion

Our analysis indicates that dietary changes toward fewer animal and more plant-based foods are associated with significant benefits due to reductions in diet-related mortality and GHG emissions. Changes in the consumption of red meat, fruits, and vegetables and in total energy intake could result in reductions in total mortality of 6–10%, compared with a reference diet in 2050. This estimate is likely an underestimate of the total impact that the dietary patterns studied here could have on diet-related mortality because we were not able to model the health consequences of changes in the consumption of all food groups. For example, diets with fewer animal-sourced foods typically include more fruits, vegetables, and more nuts and whole grains (30, 31), which evidence suggests have health benefits and are likely to increase the number of avoided deaths (4). Similarly, it is known that salt and sugar ingested in sugary drinks affect health (4), but comparative international data on their effects is insufficient to include in our models whereas the health impacts of other food groups (for example dairy) is inconclusive (35). Wherever possible, we have placed confidence estimates around our results, but we are aware that other sources of uncertainty exist that we have not been able to treat. Those uncertainties include food demand and mortality projections, possible deviations from the linear dose–response relationships linking risk factors and mortality, and our inability to remove all possible confounding effects when deriving relative risk parameters.

Our health estimates are in line with current epidemiological evidence. Tilman and Clark (12) reported results from a meta-analysis that indicated that adopting vegetarian, pescatarian, and Mediterranean dietary patterns could reduce overall mortality by 0–18%. Orlich et al. (36) reported results from a prospective cohort study, focused on vegetarian dietary patterns, that indicated reductions in mortality from all causes in vegetarians and vegans compared with nonvegetarians of 9% and 15%, respectively; and, in combining those results with two preceding prospective cohort studies, Le and Sabaté (37) reported reductions in mortality in vegetarians compared with nonvegetarians living in the United States of 12–20%. However, a prospective cohort study focused on vegetarians living in the United Kingdom found no statistically significant reduction in mortality compared with nonvegetarians (38), the reasons for which are debated (37). In general, it should be noted that inferring the health impacts of dietary patterns from observational studies is complicated by the potential presence of multiple confounding factors (even if some are controlled for).

The strength of our health analysis is that we used dose–response relationships of dietary and weight-related risk factors, such as changes in red meat consumption and overweight, that are epidemiologically more robust than the association of mortality with complete diets. With this approach, we were able to analyze differences in mortality caused by changes in consumption of specific food groups in individual regions. We found that about half of the global avoided deaths occurred because of the consumption of less red meat and that the other half was due to a combination of increased fruit and vegetable consumption and reductions in total energy intake (and the associated decreases in the fraction of people overweight and obese). However, there were marked regional variations. For example, the two areas with the greatest number of avoided deaths were East Asia and South Asia, in the former primarily driven by reduced red meat consumption and in the latter by increased fruit and vegetable consumption. Regions also differed in whether the net sum of avoided deaths was due to a modest reduction in the risk of mortality of many people or a larger reduction in the risks to a smaller population. The greatest improvement in per capita risk reductions occurred in Western high- and middle-income countries due to reduced red meat consumption and lower energy intakes.

In our environmental analysis, we project reference emissions to increase by 51% between 2005/2007 and 2050 (from 7.6 GtCO₂-eq to 11.4 GtCO₂-eq) and dietary changes to decrease the reference emissions by 29–70% (3.3–8.0 GtCO₂-eq). The latter is likely to be a conservative estimate because we did not account for the beneficial impacts of dietary change on land use through avoided deforestation. Other studies have estimated that the associated emissions reductions could amount to 2.1–2.8 GtCO₂-eq per year between 2010 and 2050 (7, 12). We also did not take into account emissions feedbacks from increased life expectancy in the dietary-change scenarios. However, such effects are likely to be small for the health impacts estimated here (SI Appendix, section SI 9).

In aggregate, our results are consistent with previous studies of the environmental consequences of dietary change. Hedenus et al. (13) projected that dietary changes (ranging from the partial replacements of ruminant meats with other meats, and of animal products with pulses and cereals) could reduce food-related GHG emissions in 2050 by 3.4–5.2 GtCO₂-eq and that technical mitigation in the agricultural sector and increased productivity could lead to additional reductions of 1.7–2 GtCO₂-eq each. Tilman and
Clark (12) projected that adopting Mediterranean, pescatarian, and vegetarian diets would reduce food-related GHG emissions in 2050 by 4.2–8.4 GtCO₂-eq, and Bajželj et al. (7) projected reductions of 5.8–6.4 GtCO₂-eq in 2050 if dietary recommendations were globally adopted. In contrast to our study, Bajželj et al. (7) included land-use emissions, and their dietary scenario is largely based on national health guidelines, which are more stringent than the global ones we used in our HGD scenario. Although we adopted the same baseline GHG emissions factors as Tilman and Clark (12), our reference estimates are slightly lower than theirs (SI Appendix, section SI.10) because we accounted for output-based productivity improvements in agriculture (which lower emissions intensities), and we did not account for the GHG emissions associated with the consumption of fish and seafood. Another difference is that we used food demand projections produced by FAO whereas Tilman and Clark generated their own income-dependent ones.

The strength of our environmental analysis is that we were able to explore regional details. For example, we found that some increases in food consumption-related GHG emissions would be necessary to achieve global dietary recommendations in Sub-Saharan Africa but that, overall, adopting global dietary recommendations would reduce the food-related per capita emissions gap between developing and developed countries (and close the gap completely if purely plant-based diets were adopted). Our analysis suggests that adopting Mediterranean diets globally would not be enough to reduce food-related GHG emissions to the same extent that total GHG emissions will need to fall to achieve a climate stabilization pathway that would have a high probability of limiting global temperature increases to below 2 °C (32). For managing food demand (including efficiency improvements in line with current trends) to make its prorated contribution, reductions in animal-based foods of the degree found only in the VGN scenario would be required. Given that such reductions would be hard to achieve, our analysis suggests that, to achieve climate stabilization, a balance will need to be struck between the degree of food demand change and the degree of adoption of plant-based diets, advances in mitigation technologies of the food sector, and disproportionate reductions in non-food-related GHG emissions.

In our economic analysis, we found that the economic value of the health benefits associated with more plant-based diets is comparable with, or exceeds, the value of the environmental benefits (depending on the valuation method used). However, although these valuation techniques are routinely used in cost-benefit analyses (20, 22), they are not strictly comparable. The value of environmental benefits techniques are routinely used in cost-benefit analyses (20, 22), they with, or exceeds, the value of the environmental benefits (depending on the valuation method used). However, although these valuation techniques are routinely used in cost-benefit analyses (20, 22), they are not strictly comparable. The value of environmental benefits techniques are routinely used in cost-benefit analyses (20, 22), they with, or exceeds, the value of the environmental benefits (depending on the valuation method used). 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Economic Co-operation and Development (OECD) (21). Following OECD recommendations, we adopted a VSL base value for the European Union (EU) of €150 000 (85–250 000 per capita pair) for direct costs ($94 000–250 000 per capita pair) to allow for a benefit transfer method to calculate VSLs in other regions (22), taking into account differences in income expressed as GDP per capita adjusted for purchasing power parity (PPP) and projected to 2050 (SI Appendix, section SI.4). We also monetized the health impact in terms of years of life lost (YLL) by using the value of statistical life year (VSLY). We calculated the VSLY for each region by expressing the VSL as the discounted net present value of the VSLY throughout a lifetime, adopting a discount rate of 3% and a maximum age of 86 adapted from the Global Burden of Disease standard life table. We used nonlinear programming (GAMS, NLP solver) to numerically solve for the VSLYs per region (SI Appendix, section SI.4).

To implement the Col approach, we used a cost transfer method to estimate the costs of illness in different parts of the world. This technique is similar to the benefit transfer method described above, and it has been used in other global assessments (34). We based our cost-of-illness estimates on a comparative assessment of the economic burden of cardiovascular diseases (23, 24) and cancer (25) across the EU. We adopted the total cost estimate associated with CHD, stroke, and cancer for the EU in 2009, which included direct costs (healthcare expenditure, health service utilization, expenditure on medication) and indirect costs (opportunity costs of informal care, productivity costs due to mortality and morbidity), calculated costs per death based on mortality statistics (26), and estimated the costs per death by disease in the EU and other regions in 2050 by scaling the base values by the ratio of health expenditure per capita for direct costs and by the ratio of GDP per capita (adjusted for purchasing power parity) for indirect costs (SI Appendix, section SI.4). Productivity losses due to morbidity and mortality, which are a part of the indirect costs, were included only for deaths occurring among adults of working age (<65 y old). For the Col analysis related to diabetes (SI Appendix, section SI.4), we adopted country-specific cost estimates (48) and, to avoid double-counting of cardiovascular disease-related complications, adjusted those estimates for the incremental cost component specifically attributable to diabetes (49, 50).

In the economic valuation of the environmental effects of dietary change, we estimated the monetary value of changes in GHG emissions. We used estimates of the social cost of carbon (SCC), which represents the monetized damages associated with an incremental increase in carbon emissions. The values adopted are based on a comprehensive integrated-assessment modeling exercise facilitated by technical experts from several US agencies (20). For the year 2050, the SCC estimates are 27, 71, 98, and 221 US dollars per ton of CO2 for discount rates of 5%, 3%, and 2.5%, and the 95th percentile at a 3% discount rate. The last value is designed to represent the possible higher than expected economic impacts from climate change further out in the tails of the SCC distribution (20).

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