

Global and regional health impacts of future food production under climate change: a modelling study*

Appendix

Table of Contents

Appendix A1: IMPACT description	2
Appendix A2: Socio-economic and emissions pathways	14
Appendix A3: Conversion from food demand into food consumption	21
Appendix A4: Weight estimation	22
Appendix A5: Description of comparative risk assessment framework	35
Appendix A6: Relative risk parameters	37
Appendix A7: Regional aggregation	41
Appendix A8: Supplementary agricultural results	46
Appendix A9: Supplementary health results	61
Appendix A10: Research in context	79
Appendix A11: Supplementary discussion	80
References	82

* Please note that this is the final draft (post-refereeing) and not identical to the publisher's version. The Lancet holds the copyright of the published article which can be accessed via [http://dx.doi.org/10.1016/S0140-6736\(15\)01156-3](http://dx.doi.org/10.1016/S0140-6736(15)01156-3).

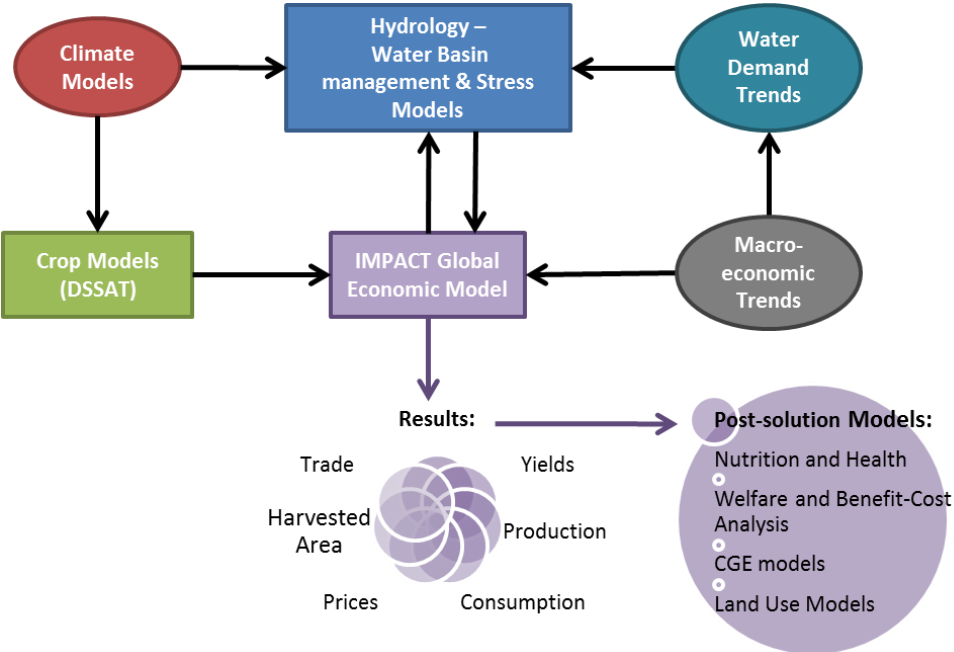
Appendix A1: IMPACT description

The IMPACT model was developed at IFPRI at the beginning of the 1990s to address a lack of long-term vision and consensus among policy-makers and researchers about the actions that are necessary to feed the world in the future, reduce poverty, and protect the natural resource base. Over time, this economic model has been expanded and improved, and IMPACT is now a network of linked economic, water, and crop models. At IMPACT's core is the original partial equilibrium multi-market model of global production, demand, and trade, which is linked to a suite of water models. The multi-market model focuses on national and global markets, including 159 countries. Agricultural production is specified by models of land supply, allocation of land (irrigated and rainfed) to crops, and determination of yields (which is described in more detail below). Production is modelled at a sub-national level, including 320 regions called "food production units" or FPUs. The FPUs are defined to link to the water models and correspond to river basins within national boundaries—154 basins and 159 countries.

The multi-market model simulates 62 agricultural commodity markets, which represent the bulk of food and cash crops. The multi-market model is integrated with the IMPACT water models, which simulate the availability of water for irrigation and the effects of changes in water availability on agricultural production. Similar to the global multi-market model, the water models operate at disaggregated scales. However the regions of interest for the water models are hydrological basins (i.e. Nile, Amazon, Mississippi, etc.), of which there are 154. To allow for the communication between the multi-market and water models, the IMPACT suite of models operates on a subnational unit, focusing on the 320 FPUs created by the intersection of the 156 geopolitical and 154 hydrological regions.

The IMPACT core is additionally connected to a series of modules integrating information from climate models (general circulation models, or GCMs), crop simulation models, population and demographic models, and economic growth models. These models are not dynamically linked like the water and multi-market models, with one-way communication of model results serving as IMPACT scenario inputs. Figure A1.1 describes the links between the different models that constitute the IMPACT system of models. We used IMPACT 3.1 for this study. Detailed model descriptions are provided by the IMPACT Development Team.^{1,2} The following sections draw on those descriptions, in particular on the description of IMPACT 3.²

Figure A1.1: The IMPACT system of models



A1.1. IMPACT Multi-Market Model

The IMPACT model system, as described in the preceding sections, is organized around a core global partial equilibrium multi-market model of agricultural production, demand, trade, and prices. The multi-market model simulates the operation of national and global markets for agricultural commodities, solving for equilibrium prices and quantities. The model specifies supply and demand behaviour in all markets. This section describes the elements of that model.

Crop Production

Crop production in IMPACT is simulated through area and yield response functions. (In IMPACT, area is treated as harvested area, which is the total area planted and harvested within a year, and may include multi-cropping or multiple harvests and differ from total arable land or reported physical area). The choice of specifying crop production in this way has a long history in IMPACT and facilitates interaction with commodity experts and land-use specialists, who work in natural units (hectares, tons/hectare). Crop production in IMPACT is specified sub-nationally with the area and yield functions at the level of Food Production Units (FPU). This regional disaggregation permits linking with water models and provides the added benefit of smaller geographical units for aggregating climate change results, which can vary significantly from one location to another. Land used for crop production is divided into irrigated and rainfed systems, capturing the significant differences in yields observed across these cultivation systems and linking directly with the water models which treat irrigated and rainfed water supplies separately.

A new feature of IMPACT 3 is the implementation of a land market to manage competing demands for agricultural land from different crops, as well as providing new linkage points to land-use models that work with broader land-use changes, such as conversion of forest to grasslands and agricultural land. It also allows us to separate total area supply (irrigated and rainfed) from individual crop area demands, and allows equilibrium conditions to determine the best economic use of the available land. The total supply of land is assumed to be a function of the “scarcity value” or “shadow price index” of land, which can also be considered a summary of changes in crop prices. The shadow price (WF) is indexed to 1 in the first year and changes based on changing demands from all crops for land area.

$$\begin{aligned}
 QFS_{fpu,Ind} &= QFSInt_{fpu,Ind} \times QFSInt2_{fpu,Ind} \\
 QFS &= \text{Land supply} \\
 QFSInt &= \text{Land supply intercept (base year supply)} \\
 QFSInt2 &= \text{Land supply growth multiplier} \\
 fpu &= \text{Food production unit} \\
 Ind &= \text{Land type (i.e. irrigated, rainfed)}
 \end{aligned} \tag{1}$$

The supply of land is considered exogenous within each year, meaning that farmers are not allowed to adjust the total crop area in the middle of the year. The total land supply over time is driven by exogenous trends on the availability of area for agriculture, as well as endogenous responses to changes in area demand, which is handled in between years. The following equation is applied at the end of each year before solving for a new year.

$$\begin{aligned}
 QFSInt2_{fpu,Ind,t+1} &= QFSInt2_{fpu,Ind,t} \times \left(1 + Landgr_{fpu,Ind}\right) \times \left(\frac{WF_{fpu,Ind,t}}{\langle WF_{fpu,Ind,t} \rangle_{t-3}}\right)^{L\gamma} \\
 Landgr &= \text{Exogenous land supply growth rate} \\
 \langle WF_{fpu,Ind,t} \rangle_{t-3} &= \text{Average shadow price of past 3 years} \\
 L\gamma &= \text{Land supply elasticity}
 \end{aligned} \tag{2}$$

Crop area is specified as an area demand function with respect to changes in the marginal revenue product, changes in land cost, and exogenous non-price trends in harvested area. Crop area elasticities simulate the supply response to changes in the marginal revenue of land represented by the following equation as the interaction of the net price of an activity and the productivity of the activity in using an additional hectare of land.

$$MRP_{j,fpu,Ind} = Yld_{j,fpu,Ind} \times PNET_{j,cty}$$

MRP = Marginal revenue product of land
 Yld = Crop yield
 $PNET$ = Net price for the activity at the country-level mapped to fpu
 j = Activity (crop)
 cty = Country

(3)

The exogenous trend in harvested area captures changes in area resulting from factors other than direct market effects, such as government programs encouraging cropping expansion, or contraction due to soil degradation, or conversion of land from agriculture to nonagricultural uses. The combination of these endogenous and exogenous factors in area demand are described in the following equation.

$$Area_{j,fpu,Ind} = Arealnt_{j,fpu,Ind} \times Arealnt2_{j,fpu,Ind} \times WF_{fpu,Ind}^{WF\epsilon} \times \left(\frac{MRP_{j,fpu}}{MRP0_{j,fpu}} \right)^{A\epsilon}$$

$Area$ = Final crop area
 $Arealnt$ = Crop area intercept (base year crop area)
 $Arealnt2$ = Exogenous crop area growth multiplier
 $WF\epsilon$ = Elasticity of demand with respect to land shadow price
 $MRP0$ = Base year marginal revenue product (used to index prices)
 $A\epsilon$ = Elasticity of area demand with respect to marginal revenue product

(4)

Assumptions for exogenous trends are determined by a combination of historical changes in land use and expert judgment on potential future regional dynamics. They are represented as compound growth from the base and are applied between years.

$$Arealnt2_{j,fpu,Ind,t+1} = Arealnt2_{j,fpu,Ind,t} \times (1 + Areagr_{fpu,Ind})$$

$Areagr$ = Exogenous area demand growth rate

(5)

Competing demands from different crops are handled through an equilibrium equation that determines the land allocation and ensures that all crop area demand must sum up to the total land supply for each FPU.

$$QFS_{fpu,Ind} = \sum_j Area_{j,fpu,Ind}$$
(6)

Crop yields are a function of commodity prices, prices of inputs, available water, climate, and exogenous trend factors. The IMPACT model includes four ways that changes in yields are achieved. First, the model assumes a scenario of underlying improvements in yields over time that, to varying degrees, continue trends observed over the past 50-60 years in an informed extrapolation following the concepts introduced in Evenson and Rosegrant,³ and Evenson and colleagues.⁴ These long-run trends, or intrinsic productivity growth rates (IPRs), are intended to reflect the expected increases in inputs, improved seeds, and improvements in management practices. These trends differ and are generally higher for developing countries, where there is considerable scope to narrow the gap in yields compared to developed countries. These IPRs are exogenous to the model, and changes in them are specified as part of the definition of different scenarios. We assume that these underlying trends vary by crop and region, and that they will decline somewhat over the next fifty years as the pace of technological improvements in developed countries slows, and as developing countries “catch up” to yields in developed countries.

Second, the IMPACT model includes a short-run (annual), endogenous, response of yields to changes in both input and output prices. These yield response functions specify the change in yield as a constant elasticity function of the changes in output prices, with elasticity parameters that can vary by crop and region. The underlying assumption is that farmers will respond to changes in prices by varying the use of inputs, including inputs such as fertilizer, chemicals, and labour that will, in turn, change yields.

Third, climate is assumed to affect yields through two mechanisms. The first mechanism is through the effects of changes in temperature and “weather” due to climate change on crop yields for rainfed and irrigated crops, as calculated from the solution of a crop simulation model (DSSAT^{5,6}) for different climate change scenarios. These crop simulations vary by crop type. The DSSAT model is run with detailed time, geographic, and crop

disaggregation for different climate change scenarios that are “downscaled” to include weather variation over small geographic areas. This analysis gives changes in average yields due to climate change that are then averaged to generate yield shocks by crop and region (FPU) in the IMPACT model. These long-run climate scenarios generate yield shocks that are assumed to follow simple trends over time, and do not consider extreme events such as droughts or floods.

The fourth mechanism by which climate change affects yields is through variation in water availability for agriculture year-by-year under different climate scenarios. This mechanism is modelled through the use of the IMPACT water models. These include: (1) a global hydrology model that determines run off to the river basins included in the IMPACT model; (2) water basin management models for each FPU that optimally allocate available water to competing non-agricultural and agricultural uses, including irrigation; and (4) a water allocation and stress model that allocates available irrigation water to crops and, when the water supply is less than demand by crop, computes the impact of the water shortage on crop yields accounting for differences among crops and varieties. These yields shocks are then passed to the IMPACT model, affecting year-to-year crop yields.

$$Yield_{j,fpu,Ind} = YieldInt_{j,fpu,Ind} \times YieldInt2_{j,fpu,Ind} \times WatShk_{j,fpu,Ind} \times CliShk_{j,fpu,Ind} \times \left(\frac{PNET_{j,cty}}{PNET0_{j,cty}} \right)^{Y\varepsilon} \times PF^{F\varepsilon}$$

Yield = Final yield
YieldInt = Yield intercept (base year yield)
YieldInt2 = Exogenous yield growth multiplier
WatShk = Water stress shock (from water models)
CliShk = Climate change shock (from water and crop models)
 $Y\varepsilon$ = Yield supply elasticity with respect to net price
 PF = Input prices
 $F\varepsilon$ = Yield supply elasticity with respect to input prices

Final crop production for each FPU and crop (j) is estimated as the product of the solution for its respective area and yield equations, with national production ($QS_{j,cty}$) equal to the summation of the production in all of the relevant FPUs in that country.

$$QS_{j,cty} = \sum_{fpu,Ind} (Area_{j,fpu,Ind} \times Yield_{j,fpu,Ind}) \quad (8)$$

Livestock Production

Livestock production is modelled at the FPU level and includes animal numbers, with associated feed demands, and meat/dairy production based on “processing” the animals. Similar to the crop sector, this specification allows for easier translation of information from livestock experts who are used to working with herd-size and feeding requirements. In the current version of the model, there is no modelling of herd dynamics—herd size over time is set exogenously.

Feed demand is a function of the livestock’s own price, the prices of intermediate (feed) inputs, and a trend variable reflecting growth in livestock herds (slaughter rates are implicitly assumed to stay more or less constant over time). The price elasticities in the livestock supply function are derived in a similar fashion to the crop area and yield elasticities.

$$Animals_{j,fpu,livsys} = AnimalInt_{j,fpu,livsys} \times AnimalInt2_{j,fpu,livsys} \times \left(\frac{PNET_{j,cty}}{PNET0_{j,cty}} \right)^{AN\epsilon} \times \prod_{cfeeds} \left(\frac{PC_{c,cty}}{PC0_{c,cty}} \right)^{Feed\epsilon}$$

Animals = Number of producing animals

AnimalInt = Animal intercept (initial number of animals)

AnimalInt2 = Exogenous population growth

PC = Consumer prices

PC0 = Initial consumer prices

Feedε = Supply elasticity with respect to changes in feed prices

livsys = Livestock production systems

cfeeds = Feed commodities demanded by livestock sector

(9)

Livestock yields are determined through exogenous growth due to improved animals and management practices. Currently, all price responses in the livestock sector are accounted for in the animal number equations.

$$AnimalYield_{j,fpu,livsys} = AnimalYieldInt_{j,fpu,livsys} \times AnimalYieldInt2_{j,fpu,livsys}$$

AnimalYield = Animal yields

(10)

AnimalYieldInt = Initial animal yields

AnimalYieldInt2 = Exogenous yield growth

Total national production ($QS_{j,cty}$) is calculated by multiplying the slaughtered number of animals by the yield per head and summing across FPU and livestock system.

$$QS_{j,cty} = \sum_{fpu,livsys} (Animals_{j,fpu,livsys} \times AnimalYield_{j,fpu,livsys}) \quad (11)$$

There is work underway to improve the livestock model, incorporating more animal types, a number of different feed “systems” that include pastures, fodders, and processed feeds, as well as feed grains, and also a more detailed representation of the value chain from feeds to herds to final demand commodities.

Production of Processed Goods

Modelling of processed goods (i.e. food oils, oil meals, sugar) has been an active area of improvement for IMPACT 3, and the development of the activity-commodity framework allows for a general handling of all processed goods in IMPACT through Input-Output matrices (IOMATs) and the use of net prices. The IOMATs represent technical coefficients on input requirements and are specified by quantities of inputs per unit of output (i.e. mt of soybeans per mt of soybean oil), and are calculated from the base data. The net price is the price the producer receives net of input costs. The net price will equal the producer price of the activity whenever there are no intermediate inputs. (Crops and livestock currently do not include intermediate inputs in the PNET equation, and instead directly take input price effects through supply elasticities in the crop yield, and animal number equations).

$$PNET_{j,cty} = PP_{j,cty} - \sum_{inputs} (IOMAT_{inputs,j,cty} \times (1 - CSEI_{inputs,cty}) \times PC_{inputs,cty})$$

PNET = Net price

PP = Producer price

PC = Consumer price of inputs

(12)

CSEI = Consumer support estimate on intermediate inputs

IOMAT = Input-output matrix

inputs = Set of commodities (c) that are inputs into activity j

Production of processed goods are then simulated by a supply function that incorporates both endogenous price effects, as well as exogenous technological change. As opposed to crop and livestock production, processed goods are modelled at the country level instead of at the FPU.

$$QS_{j,cty} = QSInt_{j,cty} \times QSINT2_{j,cty} \times \left(\frac{PNET_{j,cty}}{PNET0_{j,cty}} \right)^{QS\varepsilon}$$

QS = Total production
 QSInt = Initial production
 QSInt2 = Exogenous productivity growth
 QS\varepsilon = Supply elasticity with respect to net price

Commodity Supply and Demand

Total supply of commodities requires mapping from output of production activities to supply of commodities. The mapping is given by:

$$QSUP_{c,cty} = \sum_j JCRatio_{j,c} \times QS_{j,cty}$$

QSUP = Total commodity supply
 JCRatio = Activity to commodity mapping
 c = Commodity
 cty = Country

The parameter *JCRatio* maps from the activity output to commodities. Usually, each activity produces a matched commodity (e.g., wheat growing activity produces the commodity wheat, and nothing else). The specification, however, is general. There can be many activities producing the same commodity (e.g., different wheat growing activities producing the same wheat commodity) or a single activity producing more than one commodity (e.g., oil seed processing yielding both oil and meal). By convention, the units of *j* agree with the units of the main commodity produced by the activity (e.g., output of the wheat activity yields the commodity wheat, in the same units), so that the *JCRatio* for this mapped commodity always equals one. Other outputs, if any, from an activity in *JCRatio* are measured as a ratios to the output of the main activity (e.g., tons of meal per ton of production of oil in an oilseed processing plant).

Total domestic demand for a commodity is the sum of household food demand, agricultural intermediate demand (feed, and for process goods), and intermediate demand from other sectors (i.e. biofuels, and industrial uses).

$$QD_{c,cty} = \sum_h (QH_{c,h,cty}) + QInterm_{c,cty} + QL_{c,cty} + QBF_{c,cty} + QOTH_{c,cty}$$

QD = Total commodity demand
 QH = Household food demand
 QInterm = Intermediate demand from Ag-processing sector
 QL = Feed demand from livestock sector
 QBF = Intermediate demand for biofuel feedstock
 QOth = All other demand
 h = Household type

Food demand is a function of the price of the commodity and the prices of other competing commodities, per capita income, and total population. Per capita income and population increase annually according to country-specific population and income growth rates. Population and GDP trends vary by scenario and are drawn from the Shared Socio-economic Pathway (SSP) database representing socio-economic scenarios from the IPCC's 5th report (see Appendix A2 for more details).⁷ The IMPACT demand elasticities are originally based on USDA estimated elasticities and adjusted to represent a synthesis of average, aggregate elasticities for each region, given the income level and distribution of urban and rural population.⁸ Over time the elasticities are adjusted to accommodate the gradual shift in demand from staples to high value commodities like meat, especially in developing countries. This assumption is based on expected economic growth, increased urbanization, and continued commercialization of the agricultural sector. IMPACT is designed to simulate multiple types of households (i.e. rural, urban, rich, poor, etc.); however, currently, IMPACT treats household demand with one representative consumer per country.

$$QH_{c,h,cty} = QHInt_{c,h,cty} \times \left(\frac{pcGDR_{h,cty}}{pcGDP0_{h,cty}} \right)^{Inc\varepsilon} \times \left(\frac{(1 - CSE_{c,cty}) \times PC_{c,cty}}{(1 - CSE0_{c,cty}) \times PC0_{c,cty}} \right)^{HF\varepsilon}$$

$$\times \prod_{cc \neq c} \left(\frac{(1 - CSE_{cc,cty}) \times PC_{cc,cty}}{(1 - CSE0_{cc,cty}) \times PC0_{cc,cty}} \right)^{HF\varepsilon} \times \frac{PopH_{h,cty}}{PopH0_{h,cty}}$$

QH = Household food demand

$QHInt$ = Initial household food demand

$pcGDP$ = Per capita GDP

$pcGDP0$ = Initial per capita GDP

CSE = Consumer support estimate

$CSE0$ = Initial consumer support estimate

$PopH$ = Population disaggregated by household type

$PopH0$ = Initial household population

$Inc\varepsilon$ = Income demand elasticity

$HF\varepsilon$ = Price demand elasticity

$$\left(\frac{(1 - CSE) \times PC}{(1 - CSE0) \times PC0} \right)^{HF\varepsilon} = \text{Own-price response}$$

$$\prod_{cc \neq c} \left(\frac{(1 - CSE) \times PC}{(1 - CSE0) \times PC0} \right)^{HF\varepsilon} = \text{Cross-price response}$$

(16)

Feed demand is a derived intermediate demand. It is determined by two components: (1) animal feed requirements determined by livestock production and livestock feed requirements and (2) price effects that take into account potential substitution possibilities among different feeds. The equation also incorporates a technology parameter that indicates improvements in feeding efficiencies over time.

$$QL_{c,cty} = \sum_{j \in jlst} (QS_{jlst,cty} \times Re q_{jlst,c,cty}) \times \prod_{c \in feeds} \left(\frac{PC_{c,cty}}{PC0_{c,cty}} \right)^{LFD\varepsilon}$$

QL = Total feed demand for livestock sector

QS = Total production of each livestock activity

$Re q$ = Feed requirements for each livestock activity

$LFD\varepsilon$ = Price elasticity of demand for feed

$jlst$ = Set of livestock producing activities

(17)

Intermediate demand is a derived demand that is based on the demand for final processed goods, such as food oils and sugar. The input-output matrix determines the proportions of inputs (c) required for each producing activity (j).

$$QDInterm_{c,cty} = \sum_j (IOMat_{c,j,cty} \times QS_{j,cty})$$

$QDInterm$ = Intermediate demand

$IOMat$ = Input-Output matrix

(18)

Exogenous biofuel feedstock demand is determined through exogenous growth rates which represent government mandates to encourage the production of biofuels, though adjusted in various scenarios where the mandates are infeasible, or adjusted to reflect scenarios on the role of first or second generation biofuels. The biofuel feedstock demand equation also allows for a price response for biofuels to allow for substitution across different potential feedstocks, as well as to reflect the reality that increasing food prices would put pressure to ease biofuel mandates.

$$QBF_{c,cty} = QBFInt_{c,cty} \times QBFINT2_{c,cty} \times \prod_c \left(\frac{PC_{c,cty}}{PC0_{c,cty}} \right)^{BF\epsilon}$$

QBF = Biofuel feedstock demand
 $QBFInt$ = Initial demand from biofuel sector
 $QBFInt2$ = Exogenous growth in demand from biofuels
 $BF\epsilon$ = Price elasticity of demand for biofuel feedstock

Other demand summarizes all other demands for agricultural products from sectors outside of the focus of IMPACT (e.g. seeds, industrial use, etc.). It is simulated under two different equations. The primary method follows the household food demand equation, and is sensitive to changes in income, population and prices.

$$QOth_{c,cty} = QOthInt_{c,cty} \times \left(\frac{pcGDP_{cty}}{pcGDP0_{cty}} \right)^{IOth\epsilon} \times \left(\frac{POP_{cty}}{POP0_{cty}} \right) \times \prod_{cc} \left(\frac{PC_{c,cty}}{PC0_{c,cty}} \right)^{POth\epsilon}$$

$QOth$ = Other Demand
 $QOthInt$ = Initial other demand
 $IOth\epsilon$ = Income demand elasticity for other demand
 $POth\epsilon$ = Price demand elasticity for other demand

Markets, Trade, and Equilibrium Prices

The system of equations is written in the General Algebraic Modeling System (GAMS) programming language.⁹ The solution of these equations is achieved by the Path solver, which is included in the GAMS system. This procedure finds a set of domestic and world prices for all crops that “clear” domestic and international commodity markets. The world price (PW) of a commodity is the equilibrating mechanism for traded commodities—when an exogenous shock is introduced in the model, PW will adjust to clear world markets and each adjustment is passed back to the effective producer (PS) and consumer (PD) prices via the price transmission equations. Changes in domestic prices subsequently affect commodity supply and demand, necessitating their iterative readjustments until world supply and demand balance and world net trade again equals zero. For non-traded commodities, domestic prices in each country adjust to equate supply and demand within the country.

IMPACT assumes a closed world economy—at the end of every year the world’s production must equal the world’s demand. This constraint is ensured by the following equation, where the sum of net trade over the globe must equal zero.

$$\sum_{cty} NT_{c,cty} = 0$$

NT = Net Trade

National production and demand for tradable commodities are linked to world markets through trade. Commodity trade by country (cty) is a function of domestic production, domestic demand, and stock change. (Note that stocks are constant and exogenous). Regions with positive net trade are net exporters, while those with negative values are net importers. This specification does not permit a separate identification of international trade by country of origin and destination—all countries export to and import from a single global market.

$$NT_{c,cty} = QSUP_{c,cty} - QD_{c,cty} - QSt_{c,cty}$$

NT = Net trade
 QSt = Change in stocks

Prices are endogenous in the system of equations for food, and are calibrated to year 2005 commodity prices.¹⁰⁻¹² Prices are in constant 2005 US\$. Domestic prices of tradable commodities are a function of world prices, adjusted by the effect of trade policy represented by taxes and tariffs, price policies expressed in terms of producer support estimates (PSE), consumer support estimates (CSE), and the cost of moving products from one market to another represented by marketing margins (MM). Export taxes and import tariffs are drawn from GTAP data (Global Trade Analysis Project at Purdue University) and reflect trade policies at the national level.¹³⁻¹⁵ PSEs and CSEs represent public policies to support production and consumption by creating wedges between world and domestic prices. PSEs and CSEs are based on OECD estimates and are adjusted by expert

judgment to reflect regional trade dynamics.¹⁶ Marketing margins (MM) reflects other factors such as transport and marketing costs of getting goods to various markets and are based on expert opinion on the quality and availability of transportation, communication, and market infrastructure.

In the model, PSEs, CSEs, and MMs are expressed as percentages (ad valorem) of the world price. To calculate producer prices the appropriate wedges are applied to the domestic consumer prices (PC) and represent the mark-up observed in domestic markets from the farm-gate or factory-gate prices producers receive. The producer price of an activity is the weighted sum of the prices of the commodities associated with that activity.

$$PP_{j,cty} \times (1 + MMJ_{j,cty}) = (1 + PSE_{j,cty}) \times \sum_c JCRatio_{j,c,cty} \times PC_{c,cty}$$

PP = Producer price
 MMJ = Farm(factory)-gate to domestic market Marketing Margin (MM) (23)
 PSE = Producer support estimate, ad valorem component
 $JCRatio$ = mapping from activities (j) to commodities (c)

How consumer prices are determined in IMPACT depends on the state of tradability of the commodity. Commodities can be specified as either tradable or non-tradable. Traded commodity prices are determined in international markets. Non-traded commodities, are those commodities whose prices are determined in national markets, without direct links to international markets. Examples include sugarcane, sugar beets, and grass, where all demand is intermediate demand from domestic sectors (sugar processing, and livestock). These commodity prices are determined endogenously by country and ensure that domestic supply equals domestic demand.

$$QSUP_{c,cty} = QD_{c,cty} \quad (24)$$

Non-traded commodity are indirectly linked to world markets through the demand for final products (i.e. sugar), and potential substitution from tradable commodities (i.e. grass and other feeds).

A1.2. IMPACT Model System

The IMPACT model system is a network of linked models. Below we describe the linkages to the crop and water models used for this study. Other climatic inputs are described in Appendix A2. Again, we draw on the IMPACT model description by Robinson and colleagues for this description.² Please refer to that documentation for additional details.

Crop Models

The effect of climate change on crop yields starts by running the DSSAT family of crop models across a gridded representation of the world. Yield maps for groundnuts, maize, potatoes, rice, sorghum, soybeans, and wheat are compiled under both rainfed and irrigated conditions. Driving the model are a large collection of data. Some represent soil characteristics and conditions as well as basic management decisions while others characterize the climatic conditions under which the crops were grown.

The climate data are maps of monthly climate data that allow the random generation of daily weather data for each location typical of what might be expected for conditions of the near recent past (year 2005) as well as those of the future (year 2050). The baseline climate information come from Jones, Thornton, and Heinke.¹⁷ The future climate information is derived from data processed by the Inter-Sectoral Impact Model Intercomparison Project.¹⁸⁻²⁰ The two datasets were combined by extracting the appropriate changes from the climate model data and imposing them on the common baseline climate. The crop models can then make projections about possible yields under the different climate circumstances.

The grid-based yields for each climate and crop combination are then aggregated within regions appropriate for the economic portions of the model. Specifically, they are computed as production-area-weighted-averages using maps of production areas from the Spatial Production Allocation Model as weights.²¹ These are then used as weights in the multi-market model to estimate final yield impacts. This follows the general approach for incorporating projected yield changes from biophysical models into economics models as outlined in Müller and Robertson.²²

Water Models

The water modules in the IMPACT Modelling System include: (1) the IMPACT global hydrology model (IGHM), (2) the IMPACT water basin simulation model (IWSM) that manages storage by water basin and generates available irrigation water supply; and (3) the IMPACT crop water allocation and stress model (ICWASM) that allocates available irrigated water to crops and estimates the impact of water shortages on yields. These three models enable the IMPACT multi-market model to assess the effects on global food and water systems of hydro-climatic variability and change, socioeconomic change-driven water demand growth, investment in water storage and irrigation infrastructure, and technological improvements.

The IGHM hydrological model is driven by climate-forcing data and computes effective rainfall, potential and actual evapotranspiration, and runoff to river basins. The IGHM-simulated hydrologic outputs are then provided in a one-way link to the IWSM water basin simulation models, which optimally manage water basin storage and provide irrigated water supply in one-way link to the ICWASM water stress models that then provides the IMPACT multi-market model with crop yields for both irrigated and rainfed crops. The solution of the IGHM model depends only on climate inputs and is completely independent of the other water models and the IMPACT multi-market model. However, there is two-way communication between the IWSM model and the IMPACT multi-market model—the demand for water in IWSM depends on the allocation of land to crops, which is part the solution of the IMPACT multi-market model. In turn, changes in water availability from IWSM affect water allocation and stress in the ICWASM model. The communication between these models to capture this endogeneity is discussed below.

IMPACT Global Hydrology Model (IGHM)

As described in the following schematic (Figure 5.5), the IGHM hydrological model is a semi-distributed parsimonious model. It simulates monthly soil moisture balance, evapotranspiration and runoff generation on each 0.5° latitude x 0.5° longitude grid cell spanning the global land surface except the Antarctic. Gridded output of hydrological fluxes - namely effective rainfall, evapotranspiration and runoff - are spatially aggregated to food production units (FPU) within the river basin and weighted by grid cell areas.

The most important climatic drivers for water availability are precipitation and evaporative demand determined by net radiation at ground level, atmospheric humidity, wind speed, and temperature. In IGHM, the Priestley-Taylor equation is used to calculate potential evapotranspiration (PET).²³ Soil moisture balance is simulated for each grid cell using a single layer water bucket. To represent sub-grid variability of soil water-holding capacity, we assume it spatially varies within each grid cell, following a parabolic distribution function.

Actual evapotranspiration is determined jointly by the PET and the relative soil moisture state in a grid cell. The generated runoff is divided into a surface runoff component and a deep percolation component using a partitioning factor. The base flow is linearly related to storage of the groundwater reservoir. The total runoff to the streams in a month is the sum of surface runoff and base flow.

IMPACT Water Basin Simulation Model (IWSM)

Water demand

The water demand module calculates water demand for crops, industry, households, and livestock at the FPU level. Irrigation water demand is assessed as the portion of crop water requirement not satisfied by precipitation or soil moisture based on hydrologic and agronomic characteristics. Crop demand is calculated for each crop using evapotranspiration and effective rainfall from IGHM. It relies on the FAO crop coefficient approach to calculate actual water demand for each crop every month. Irrigation demand in the FPU is calculated for a given cropping pattern after taking into account the basin efficiency of the irrigation system.²⁴ The IMPACT multi-market model solves endogenously for the allocation of land to different crops while the IWSM model requires information on cropping pattern to calculate water demand and hence water stress that is then an input into the multi-market model, which requires two-way communication between the models (as mentioned earlier).

Industrial water demand is modelled for the manufacturing and energy sectors using growth rates for the value-added by sector and energy production values for electricity sector from the EPPA6 Model of the MIT Joint Program on the Science and Policy of Global Change.²⁵ For many countries in Sub-Saharan Africa, the projected industrial water demands are substantially lower than those in IMPACT2, suggesting an underestimation.

Therefore, for countries in Sub-Saharan Africa we retained the projection method of IMPACT2 for industrial water demand which is modelled as a nonlinear function of gross domestic production per capita and technology change.

Future domestic water demands are based on projections of population and income growth. In each region or basin income elasticities of demand for domestic water use are synthesized based on the literature and available estimates.^{26,27} These elasticities of demand measure the propensity to consume water with respect to increases in per capita income. The elasticities also capture both direct income effects and conservation of domestic water use through technological and management change. Livestock water demand is proportional to the number of animals raised as calculated by the multi-market model.

Water Supply

The IMPACT Water Basin Simulation Model (IWSM) is a water basin management model. For FPU's where there is surface water storage capacity (e.g., dams), the model specifies a single reservoir that summarizes all water storage capacity. For a given water basin that includes more than one FPU, IWSM manages storage in all those FPU's to maximize the ratio of water supply to water demand in the water basin. IWSM uses the runoff calculated by IGHM, the climatic data and the water demands presented above to allocate available water to different uses. In each FPU, IWSM solves for a balance between the change in the amount of water stored in the reservoirs, the entering water flows (runoff from precipitation, water from non-traditional sources like desalination, and inflows from FPU's situated upstream), the exiting water flows (groundwater recharge from the stream, evaporation from the reservoirs, outflows to the FPU downstream or the ocean) and the water withdrawn for human use (surface water depletion). The model uses a simple hedging rule to avoid leaving an empty storage for next year.

Surface water depletion added to the pumped groundwater (which is limited by the monthly capacity of tubewells and other pumps) is used to meet the various water demands. The model solves by maximizing the ratio of water supplied to water demanded by water basin over a year in all FPU's. Solving for water demand and supply in all FPU's simultaneously, IWSM assumes that linked FPU's within the same water basins are operated cooperatively, optimally allocating water between upstream and downstream demanders (qualified by imposing constraints on water delivery to downstream demanders). The model is parameterized to use available storage to smooth the distribution of water over months in order to avoid dramatic swings in monthly water delivery, if possible.

Following standard practice, IWSM incorporates the basic rule that non-agricultural water demands have priority over agricultural water demands. Any shortage in water supply is absorbed by agriculture first. If the shortage is larger than irrigation water demand, then livestock, domestic and industrial supplies are reduced proportionally.

IMPACT Crop Water Allocation and Stress Model (ICWASM)

The Water Allocation and Stress module (ICWASM) then allocates water among crops in an area, given the economic value of the crop. We use the FAO Ky approach to measure water stress using a monthly approach to include seasonality of water stress.²⁸ Because optimizing total value of production given fixed prices leads to a tendency for specializing in high-value crops, we include a measure of risk aversion for farmers in the objective function, which preserves a diversified production structure even in case of a drought. The stress model produces a measure of yield stress for every crop—both irrigated and rainfed—in each of FPU's where that crop is grown. The yield stress for the base year is recorded and the model defines for subsequent years the yield shock as the ratio of that year's yield stress to the base year yield stress. This allows for a consistent modelling framework while making sure that the base year yields from the multi-market model dataset is preserved.

Linking the IMPACT water and multi-market models

In a given year, the IMPACT multi-market model is first solved assuming exogenous trends on various parameters, yielding projected production, prices and allocation of land to crops. For this first run, expected water stress is set to the average of the previous four years, which sets harvest expectations for the allocation of land to different crops. This solution can be seen as providing projections that farmers use to make their cropping decisions.

The water demand module then calculates water demand for crops, industry, households, and livestock. Agricultural and non-agricultural water demands are then calculated as outlined above. IWSM uses these water

demands, along with river flows provided by IGHM, to provide the monthly repartition of water amongst FPUs given the objective function described above.

ICWASM then allocates water among crops in an area, given the economic value of the crop. The stress model produces a measure of water stress on yield for every crop—both irrigated and rainfed—in each of the FPUS that is then multiplied by the temperature stress obtained from DSSAT to represent the total climate yield shock.

Finally, the new yield shocks are applied to the IMPACT multi-market model, which is solved a second time for the final equilibrium, only now assuming that the allocation of land to crops is fixed since farmers cannot change their decisions after planting. This solution yields all economic variables, including quantities and prices of outputs and inputs, and all trade flows. The model then moves to the next year, updates various parameters on trend and starts the process again.

Appendix A2: Socio-economic and emissions pathways

Table A2.1 provides an overview of this study's model inputs and scenarios.

Table A2.1: Overview of model inputs and components used for constructing the model scenarios within the IMPACT and health analysis framework (see Panel 1 in the main text for a description of climate and development-related scenario inputs). The main scenarios include a reference scenario without climate change which follows a "middle-of-the-road" socio-economic development pathway (SSP2), and six climate change scenarios which follow the same socio-economic pathway and, in addition, a high emissions pathway (RCP8.5) with different combinations between three general circulation models (IPSL-CM5A-LR, HadGEM2-ES, MIROC-ESM-CHEM) and two crop models (DSSAT, LPJmL).

Model inputs	Model component	Main scenarios		Sensitivity analysis
		Reference scenario	Climate change scenarios	
Climatic inputs	Radiative forcing pathway	none	RCP8.5	RCP6.0
				RCP4.5
				RCP2.6
Biophysical inputs	Crop models	none	IPSL-CM5A-LR HadGEM2-ES MIROC-ESM-CHEM	DSSAT
				LPJmL
Socio-economic inputs	Socio-economic pathway	SSP2	SSP2	SSP1 SSP3
Health inputs	Relative risk parameters		RR(Δ FV; Δ red meat)	RR(Δ FV; Δ red meat)
			RR(Δ weight)	RR(Δ weight)
			Monte-Carlo analysis	Monte-Carlo analysis

Abbreviations: RCP: representative concentration pathway; SSP: shared socio-economic pathway; RR: relative risk; FV: fruit and vegetable consumption

Socio-economic pathways

For this study's main scenarios, we adopted a "middle-of-the-road" socioeconomic trajectory (SSP2), using GDP projections developed by the Organization for Economic Co-operation and Development (OECD) and population projections developed by the International Institute for Applied Systems Analysis (IIASA).^{29,30} For analysing the sensitivity to different socio-economic pathways, we adopted two alternative socio-economic pathways in the sensitivity analysis: a "Sustainability"-termed socio-economic pathway (SSP1) which is characterized by medium to high economic growth and low population growth, and a "Fragmentation"-termed socio-economic pathway (SSP3) which is characterized by slow economic growth and high population growth.³¹ The challenges to mitigation and adaptation increase when going from SSP1 to SSP3. Table A2.2 provides an overview of the storylines associated with each socio-economic pathway, and Table A2.3 lists the associated GDP and population estimates.

Table A2.2 Summary narratives of the Shared Socio-Economic Pathways (SSPs)

SSP	Narrative
SSP 1	Sustainable development is realized, with relatively high levels of investment in research and development, which leads to rapid technological change (with a sustainable focus), decreasing inequality, lower energy intensity, and high land productivity. This development pathway leads to a future where society is able to relatively easily mitigate or adapt to climate change. There is high rates of economic growth, declining population growth, and increasing levels of education globally.
SSP 2	This is a middle of the road scenario, which follows historical trends. Economic development continues, but is not uniform. Environmental degradation continues, but at a slowing pace. There is general improvement, but it is much slower than that seen in SSP 1. Climate change presents moderate challenges to both adaptation and mitigation.
SSP 3	A fairly negative future pathway characterized by increasing nationalism, with greater levels of conflict and challenges to global and regional cooperation. Barriers to trade increase, and countries tend to look inward at the expense of global cooperation. There are lower levels of technological change. Economic development is slow, and population growth is higher. Climate change presents significant challenges for both adaptation and mitigation
SSP 4	A scenario where current levels of inequality become entrenched and worsened over time. With inequality and stratification both within and between countries increasing. These leads to a world of pockets. Rich countries and elites in poorer countries improve significantly, but the rest lag behind. High levels of integration across elites allows for some level of global coordination, which allows society to more easily mitigate to climate change. However, large segment of the population are left behind, making climate change adaptation more difficult for most
SSP 5	A future characterized by fast economic industrialization. There are high levels of technological progress and improvements in education levels around the world. Globalization increases rapidly. However, the rapid industrialization is spurred on through the intense use of fossil fuels, and as such there is little effort to mitigate the effects of climate change, with the focus on adaptation through the development of new and improved technologies.

Source: Author summary from O'Neill et al 2014 and O'Neill et al 2015 descriptions of the SSPs ^{32,33}

Table A2.3 Regional summary of GDP (billion 2005 USD), population (million), and GDP per capita (000 USD/person) assumptions by SSP

	2010	2050				
		SSP1	SSP2	SSP3	SSP4	SSP5
<i>East Asia and Pacific</i>						
GDP	19,236	104,096	80,045	60,608	78,950	130,284
Population	2,184	2,173	2,261	2,351	2,145	2,187
GDP per capita	9	48	35	26	37	60
<i>Europe</i>						
GDP	14,628	30,571	27,780	21,342	28,442	39,228
Population	537	592	577	498	544	662
GDP per capita	27	52	48	43	52	59
<i>Former Soviet Union (excl. Baltic States)</i>						
GDP	2,855	10,603	8,984	7,551	9,174	13,750
Population	279	262	277	289	257	266
GDP per capita	10	40	32	26	36	52
<i>Latin America and Caribbean</i>						
GDP	5,834	22,838	19,164	15,894	17,600	27,492
Population	585	674	742	853	705	651
GDP per capita	10	34	26	19	25	42
<i>Middle East and North Africa</i>						
GDP	4,551	20,566	18,631	16,006	18,550	26,763
Population	457	646	715	808	726	649
GDP per capita	10	32	26	20	26	41
<i>North America</i>						
GDP	14,290	33,691	29,933	24,753	32,124	44,503
Population	344	460	450	372	424	535
GDP per capita	41	73	67	67	76	83
<i>South Asia</i>						
GDP	4,461	44,250	32,939	22,756	27,189	55,705
Population	1,630	2,108	2,373	2,720	2,289	2,087
GDP per capita	3	21	14	8	12	27
<i>Sub-Saharan Africa</i>						
GDP	1,705	19,690	13,962	9,665	8,843	25,499
Population	863	1,564	1,793	2,084	2,055	1,543
GDP per capita	2	13	8	5	4	17
<i>World</i>						
GDP	67,559	286,305	231,439	178,575	220,873	363,226
Population	6,879	8,479	9,187	9,975	9,147	8,578
GDP per capita	10	34	25	18	24	42

Source: Calculated from IMPACT 3.1 with population and GDP growth rates from IIASA and OECD^{29,30}

Note: GDP and GDP per capita are in purchasing power parity (ppp)

Emissions pathways

In the main climate change scenarios, we adopted the highest emissions pathway (RCP8.5) to scope the full range of potential climate change impacts. That pathway leads to an increase in the global mean surface air temperature of 2.0 degrees C in 2046-2065 compared to the period 1986-2005.³⁴ For analysing the sensitivity to different emissions pathways, we adopted three alternative emissions trajectories in the sensitivity analysis: two medium climate-stabilization scenarios (RCP4.5, RCP6), and one stringent climate-stabilization scenario (RCP2.6) that is based, in part, on the use of negative emissions technologies, such as carbon capture and storage (CCS) and bio-energy.³⁵ The increases in global mean surface air temperature from the period 1986-2005 to 2046-2065 are 1.3 degrees C and 1.4 degrees C in the medium stabilization scenarios (RCP6.0, RCP4.5), and 1.0 degree C in the stringent stabilization scenario (RCP2.6). The changes in precipitation for a given change in temperature increase when going from the low emissions scenario to the higher emissions scenarios (from RCP2.6 to RCP8.5).³⁴ Table A2.4 lists the range of changes in temperature and sea-level rise associated with each emissions pathway.

Table A2.4 Likely range of global warming and sea level rise by RCP

RCP	Mid Century ^a		End of the Century ^b	
	Temperature Increase ^c	Sea Level Rise	Temperature Increase	Sea Level Rise
2.6	+ 0.4–1.6	+ 0.17–0.32	+ 0.3–1.7	+ 0.26–0.55
4.5	+ 0.9–2.0	+ 0.19–0.33	+ 1.1–2.6	+ 0.32–0.63
6.0	+ 0.8–1.8	+ 0.18–0.32	+ 2.2–3.1	+ 0.33–0.63
8.5	+ 1.4–2.6	+ 0.22–0.38	+ 2.6–4.8	+ 0.45–0.82

Source: IPCC ⁷

Notes: The NoCC scenario assumes no change in temperature or sea levels

^a Mid Century represents the 20 years from 2046-2065

^b End of Century represents the 20 years from 2081-2100

^c Temperature is in °C, and Sea level rise is in m

Regional projections of the agricultural impacts of climate change are subject to significant uncertainty.³⁶ We therefore used different combinations of general circulation models (GCMs), which project changes in temperature and precipitation, and crop models, which use those changes to project biophysical changes in crop yields, to generate a spread of input parameters for our agriculture and health assessment. The GCMs include HadGEM2-ES,³⁷ IPSL-CM5A-LR,³⁸ and MIROC-ESM-CHEM;³⁹ and the crop models include DSSAT and LPJmL.^{6,40} The pair-wise combination of GCMs with crop models resulted in six climate change scenarios for each socio-economic and emissions pathway. We calculated the mean and standard deviation of the scenario endpoints (changes in food availability and consumption, and changes in mortality) that are associated with the different climate change scenarios, and we report those in the main text to simplify exposition. Figures A2.1- A2.2 show the regional distribution of changes in temperature and precipitation estimated by the three GCMs, and Figure A2.3 shows the regional distribution of soil types that is used by the globally gridded crop models. Appendix A1 provides additional detail on the interaction between crops models and the IMPACT global economic model

Figure A2.1 Changes in maximum temperature (in degrees Celsius) in 2050 compared to 2000 under a high-emissions trajectory (RCP8.5) estimated by HadGEM2-ES³⁷ (upper panel), IPSL-CM5A-LR³⁸ (middle panel), and MIROC-ESM-CHEM³⁹ (lower panel).

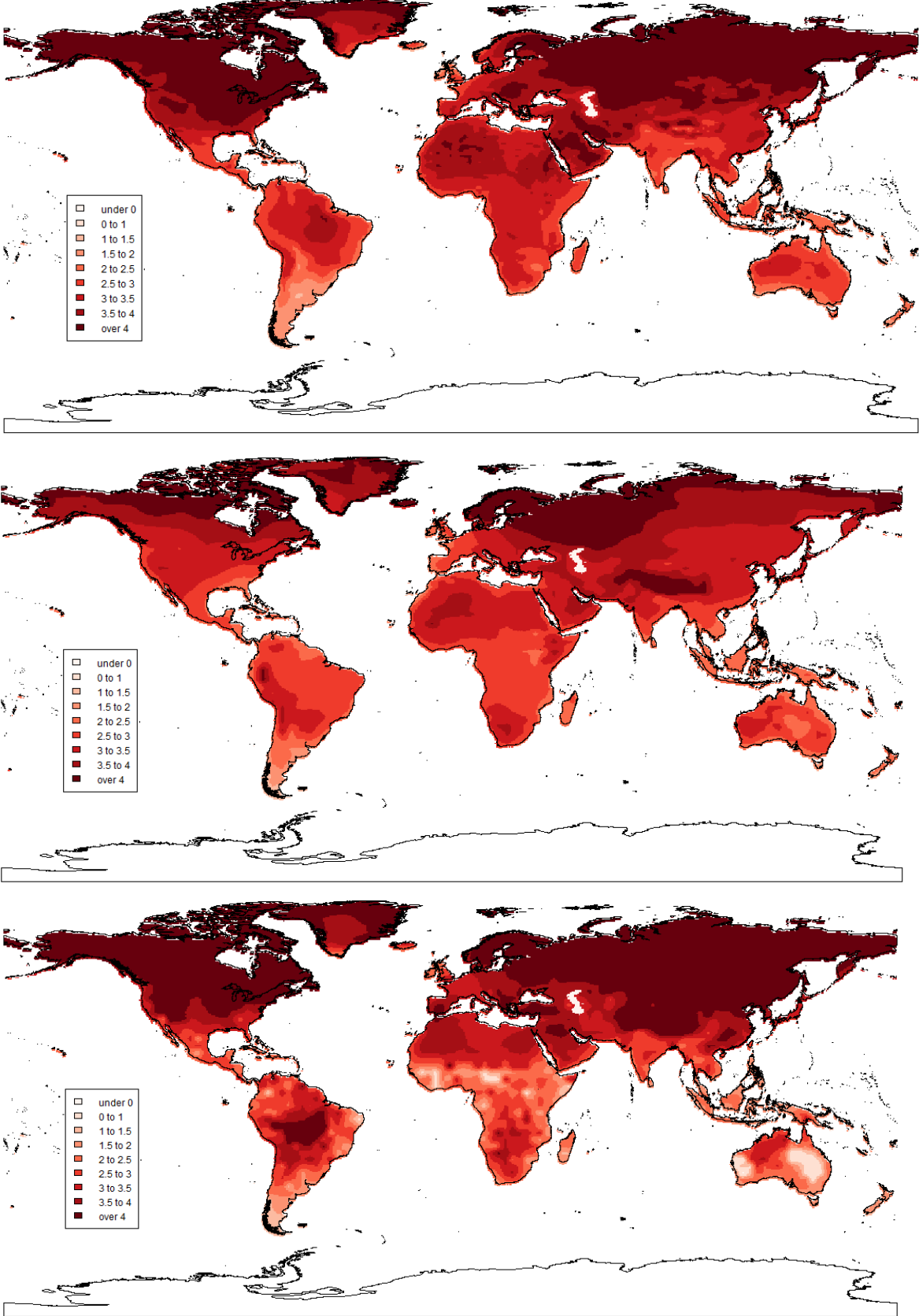


Figure A2.2 Changes in precipitation (in millimetres) in 2050 compared to 2000 under a high-emissions trajectory (RCP8.5) estimated by HadGEM2-ES³⁷ (upper panel), IPSL-CM5A-LR³⁸ (middle panel), and MIROC-ESM-CHEM³⁹ (lower panel).

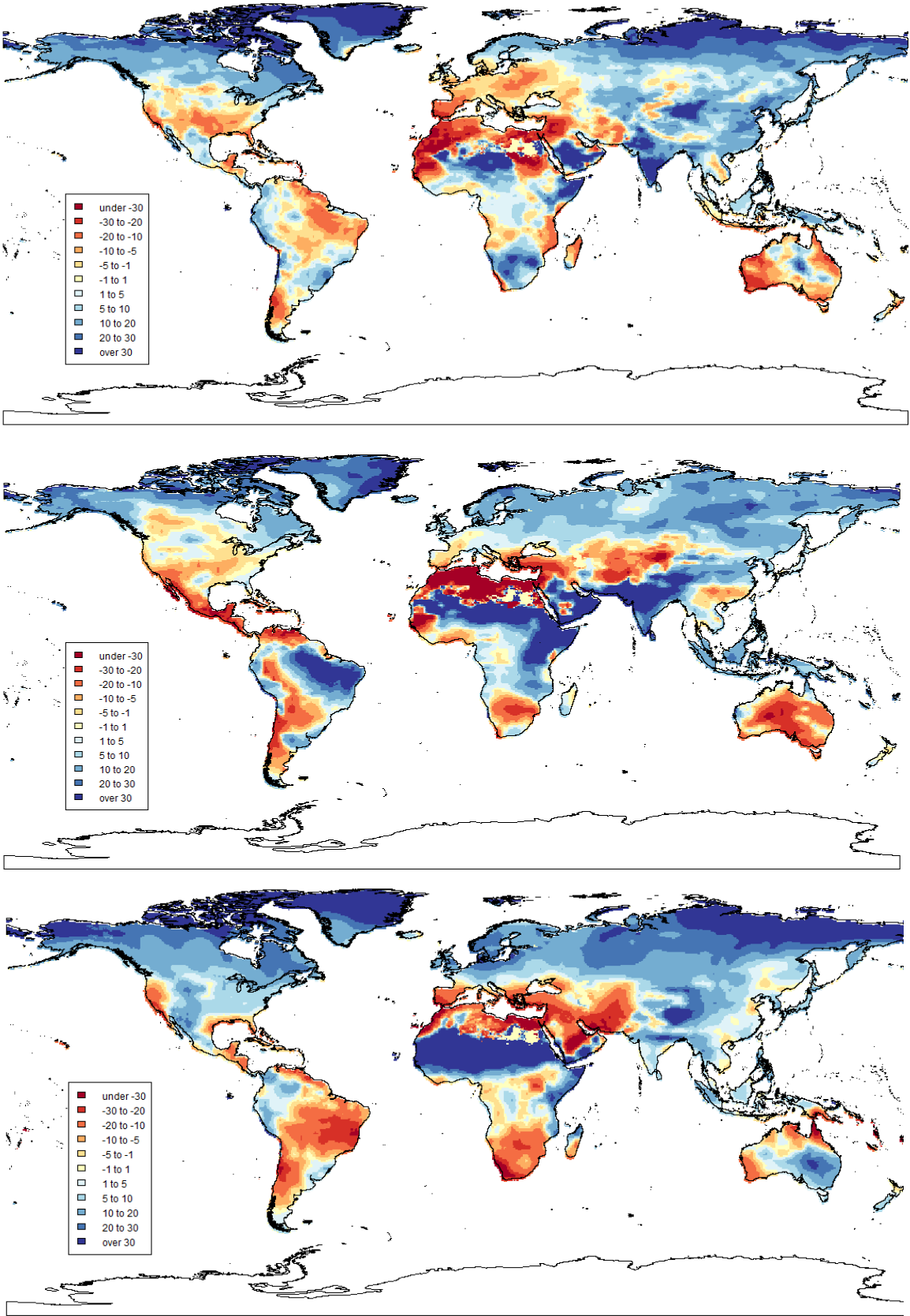
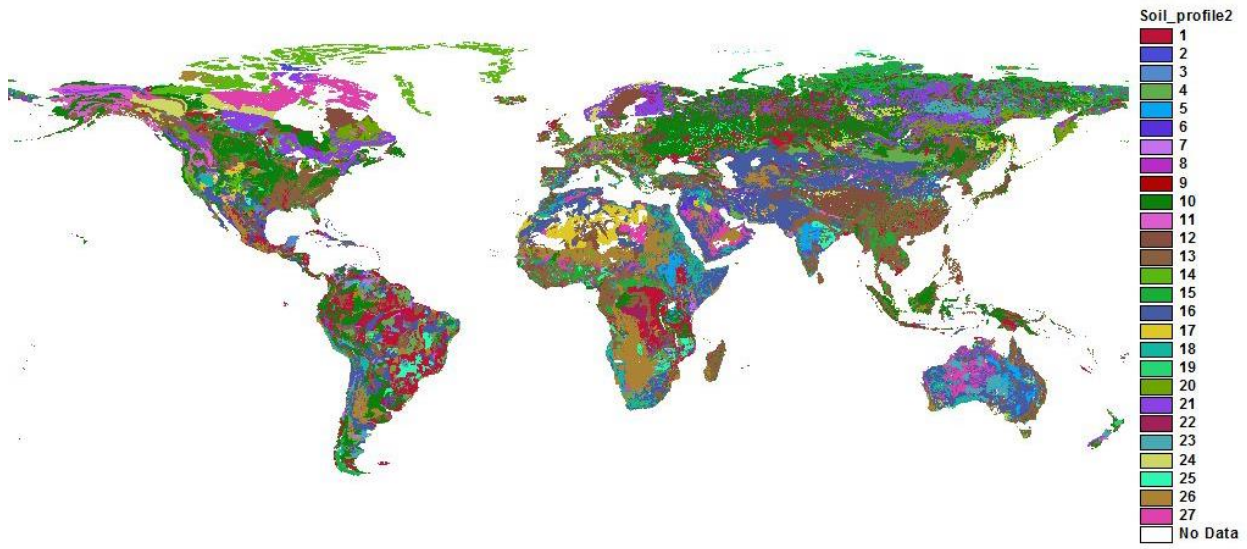


Figure A.3 Global Distribution of 27 Generic Soil Types



Source: The Harmonized World Soil Database (FAO/IIASA/ISRIC/ISSCAS/JRC 2012)

Appendix A3: Conversion from food demand into food consumption

Baseline food production and availability, as estimated by the IMPACT model, are calibrated using food balance sheets supplied by the Food and Agriculture Organization of the United Nations (FAO). The FAO states that:⁴¹⁻⁴³

The quantities of food available for human consumption, as estimated in the food balance sheet, relate to the quantities of food reaching the consumer. Waste on the farm and during distribution and processing is taken into consideration as an element in the food balance sheet. However, The amount of food actually consumed may be lower than the quantity shown in the food balance sheet depending on the degree of losses of edible food and nutrients in the household, e.g. during storage, in preparation and cooking (which affect vitamins and minerals to a greater extent than they do calories, protein and fat), as plate-waste, or quantities fed to domestic animals and pets, or thrown away.

For the dietary risk assessment, we converted the food availability estimates for fruit and vegetables and for red meat into food consumption estimates by using regional data on food wastage at the consumption level, combined with conversion factors into edible matter.⁴⁴ Table A3.1 lists the waste percentages used. A conversion factor of 0.77 was used to determine the edible parts of fruits and vegetables. No conversion factor was used for red meat, because the waste percentages reported in Table A3.1 were obtained for carcass weight (including bone), and therefore included wastage of non-edible parts.

Table A3.1: Waste percentages at consumption according to FAO⁴⁴

Food items	Regions						
	Europe	USA, Canada, Oceania	Industrialized Asia	Sub-Saharan Africa	North Africa, West and Central Asia	South and Southeast Asia	Latin America
Fruits and vegetables	0.19	0.28	0.15	0.05	0.12	0.07	0.1
Meat	0.11	0.11	0.08	0.02	0.08	0.04	0.06

Appendix A4: Weight estimation

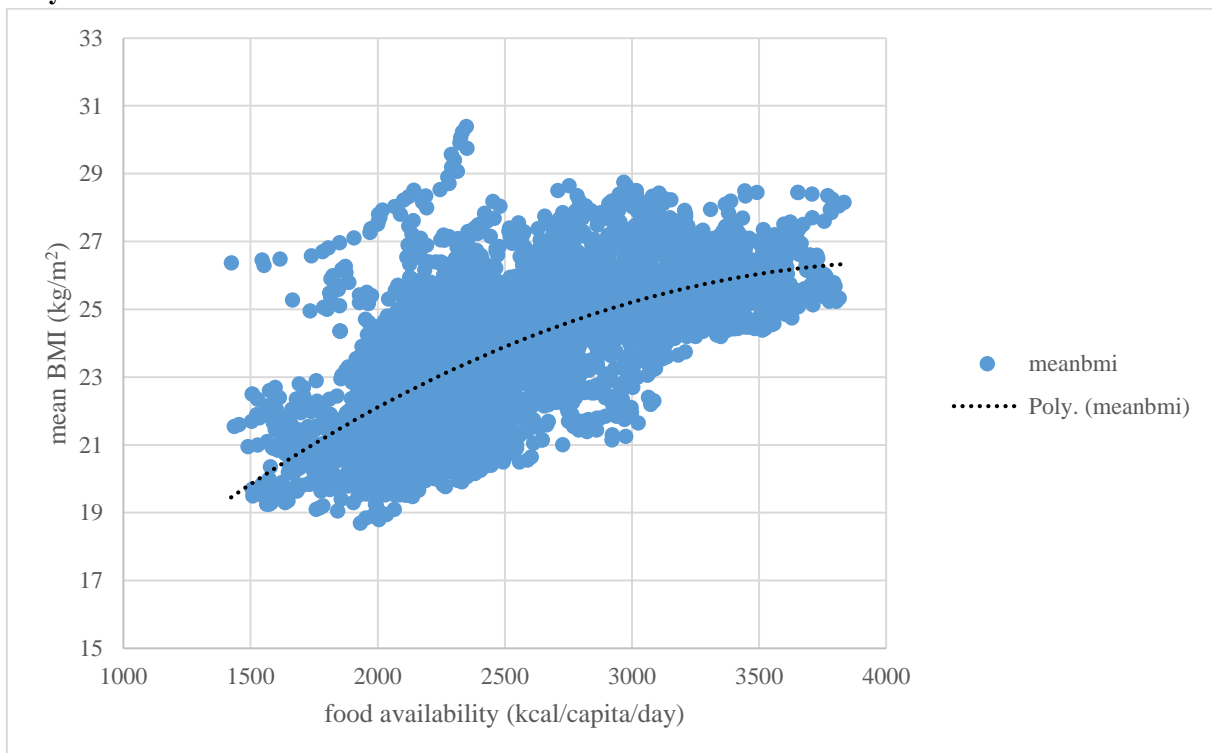
For the weight-related risk assessment, we estimated changes in weight as shifts in the baseline weight distribution by using the historical relationship between national food availability and mean BMI. We estimated the baseline distribution by fitting a log-normal distribution to WHO estimates of mean BMI and the prevalence of overweight and obesity using a cross-entropy method.⁴⁵ Cross-entropy estimation is a Bayesian technique for recovering parameters and data which have been observed imperfectly. The cross-entropy approach redefines the estimation problem as estimating and minimizing the divergence from the original prior while satisfying various constraints. In our application, we take mean BMI values as given and use the cross-entropy method to find the shape and position parameters of the log-normal distribution which jointly minimize the deviation of the estimates of the prevalence of overweight and the prevalence of obesity from the input parameters.

We estimated the relationship between national food availability and mean BMI by pairing FAO food availability data for the years 1980-2009 with WHO data on mean BMI for the same period. Using a polynomial trend yielded the following relationship ($R^2 = 0.46$):

$$BMI(r) = (-9.53 \cdot 10^{-7}) \cdot kcal(r)^2 + (7.87 \cdot 10^{-3}) \cdot kcal(r) + 10.18 \quad (25)$$

where $kcal(r)$ denotes food availability in region r in terms of kcal per person per day, and $BMI(r)$ denotes the average mean BMI in that region. Figure A4.1 provides a graphical depiction.

Figure A4.1: Association between food availability and mean BMI based on data from FAO and WHO for the years 1980-2009.



Based on the relationship between mean BMI and food availability, we estimated the changes in the weight distribution as follows. We calculated the mean BMI values for the years 2010 and 2050 using food availability projections from the IMPACT model, and we then used the percentage change in mean BMI between 2010 and 2050 to shift the baseline BMI distribution. In shifting the weight distribution, we held constant the distribution's shape parameter, $\sigma(r)$, and re-calculated its position parameter $\mu(r)$ based on the estimated mean: $\mu(r) = \log BMI(r) - \frac{\sigma(r)^2}{2}$. Analyses were conducted to assess the impact of holding the shape parameter constant, which showed that results were not sensitive to this assumption. Tables A4.1-A4.3 list the estimated weight distribution for the baseline in 2010, for the reference scenario without climate change in 2050, and for the mean of all climate change scenarios in 2050.

Table A4.1: Baseline weight distribution estimated for 2010, including food availability (kcal/cap/day), mean BMI (kg/m²), and the prevalence of underweight (BMI<18.5), normal weight (18.5<BMI<25), overweight (25<BMI<30), and obesity (BMI>30). See Appendix A6 for details on the regional aggregation.

Region	kcal/day	mean BMI	underweight	normal	obese	overweight
Global	2,817.488	23.834	0.126	0.521	0.116	0.237
HIC	3,414.266	26.521	0.049	0.380	0.242	0.329
AFR_LMIC	2,417.637	22.982	0.154	0.558	0.077	0.211
AMR_LMIC	2,886.389	26.674	0.043	0.369	0.247	0.341
EMR_LMIC	2,661.549	24.951	0.100	0.454	0.170	0.275
EUR_LMIC	3,035.427	26.310	0.056	0.388	0.231	0.324
SEA_LMIC	2,406.471	21.463	0.206	0.638	0.020	0.136
WPR_LMIC	3,016.896	22.958	0.133	0.582	0.058	0.227
AFG	2,424.123	20.897	0.276	0.588	0.017	0.120
AGO	2,368.642	23.056	0.161	0.532	0.080	0.228
ALB	2,881.118	26.202	0.051	0.396	0.219	0.334
ARG	3,150.012	27.600	0.031	0.319	0.304	0.346
ARM	2,715.527	26.429	0.059	0.380	0.242	0.319
AUS	3,142.919	27.348	0.027	0.329	0.282	0.362
AUT	3,680.203	25.782	0.062	0.418	0.198	0.323
AZE	3,090.000	26.809	0.048	0.362	0.261	0.330
BDI	2,078.599	21.498	0.228	0.595	0.026	0.150
BEN	2,503.985	23.154	0.133	0.560	0.069	0.238
BFA	2,615.127	21.502	0.199	0.645	0.016	0.140
BGD	2,473.371	20.549	0.269	0.645	0.005	0.081
BGR	2,798.138	26.133	0.054	0.399	0.217	0.330
BLR	2,874.586	26.560	0.050	0.375	0.244	0.331
BLT	3,781.702	26.244	0.060	0.390	0.229	0.321
BLX	3,772.205	26.066	0.052	0.404	0.210	0.333
BLZ	2,677.116	28.645	0.016	0.259	0.369	0.356
BOL	2,158.139	25.803	0.065	0.415	0.202	0.318
BRA	3,130.506	26.002	0.050	0.409	0.204	0.337
BTN	2,200.784	22.946	0.133	0.581	0.057	0.229
BWA	2,174.990	24.249	0.148	0.450	0.151	0.251
CAF	1,959.224	21.862	0.202	0.595	0.033	0.170

CAN	3,446.720	27.147	0.028	0.341	0.268	0.363
CHL	2,899.668	27.655	0.025	0.313	0.304	0.358
CHM	3,102.757	23.000	0.130	0.580	0.058	0.232
CHP	3,355.467	25.182	0.073	0.452	0.164	0.311
CIV	2,655.107	23.286	0.125	0.558	0.072	0.245
CMR	2,318.619	24.451	0.090	0.494	0.125	0.291
COD	1,761.194	20.906	0.254	0.625	0.011	0.110
COG	2,221.470	22.650	0.158	0.577	0.053	0.212
COL	2,682.323	25.709	0.062	0.422	0.192	0.323
CRB	3,172.060	27.751	0.032	0.312	0.316	0.340
CRI	2,863.140	26.895	0.035	0.357	0.256	0.352
CUB	2,471.888	26.245	0.053	0.393	0.224	0.331
CYP	2,547.221	26.764	0.049	0.364	0.258	0.329
CZE	3,336.967	27.336	0.042	0.335	0.293	0.330
DEU	3,506.013	26.435	0.045	0.383	0.231	0.341
DJI	2,165.708	23.948	0.123	0.499	0.114	0.263
DNK	3,315.047	25.696	0.051	0.429	0.182	0.338
DOM	2,473.269	26.498	0.045	0.379	0.236	0.340
DZA	3,073.851	25.640	0.066	0.425	0.191	0.318
ECU	2,231.460	26.449	0.043	0.382	0.231	0.343
EGY	3,244.642	28.492	0.021	0.271	0.361	0.347
ERI	1,816.848	21.051	0.232	0.645	0.011	0.112
ETH	2,116.363	20.600	0.269	0.639	0.006	0.086
FJI	2,928.756	28.119	0.025	0.292	0.337	0.345
FNP	3,160.332	26.240	0.047	0.394	0.219	0.340
FRP	3,498.666	25.317	0.068	0.446	0.169	0.317
GAB	2,687.270	25.197	0.076	0.449	0.167	0.308
GEO	2,866.925	26.176	0.059	0.395	0.224	0.323
GHA	2,768.978	23.757	0.107	0.535	0.090	0.267
GIN	2,515.772	22.600	0.150	0.595	0.046	0.209
GMB	2,426.269	23.416	0.149	0.514	0.096	0.241
GNB	2,383.395	22.354	0.191	0.559	0.054	0.197
GNQ	2,621.864	24.239	0.115	0.485	0.128	0.272
GRC	3,592.905	25.740	0.058	0.422	0.191	0.328
GSA	2,655.622	26.074	0.072	0.395	0.226	0.307
GTM	2,185.275	26.220	0.049	0.395	0.219	0.337
HND	2,566.495	26.050	0.054	0.404	0.210	0.332
HRV	3,055.553	26.020	0.062	0.403	0.215	0.320
HTI	1,827.035	23.798	0.106	0.533	0.092	0.269
HUN	3,420.063	26.660	0.049	0.370	0.251	0.330
IDN	2,563.645	22.547	0.154	0.595	0.045	0.206
IND	2,345.640	21.193	0.216	0.654	0.011	0.118
IRL	3,407.594	27.196	0.027	0.337	0.271	0.365
IRN	3,141.308	26.386	0.047	0.386	0.229	0.338
IRQ	2,971.592	27.640	0.025	0.314	0.303	0.358

ISL	3,247.382	26.704	0.037	0.368	0.244	0.351
ISR	3,611.191	27.351	0.033	0.332	0.288	0.347
ITP	3,742.937	25.673	0.057	0.428	0.185	0.330
JAM	2,712.633	26.834	0.054	0.360	0.267	0.320
JOR	3,114.090	28.431	0.023	0.277	0.358	0.342
JPN	2,769.861	22.680	0.133	0.611	0.042	0.214
KAZ	2,881.231	26.659	0.053	0.369	0.253	0.325
KEN	2,073.255	22.401	0.170	0.586	0.046	0.199
KGZ	2,763.448	25.406	0.080	0.432	0.185	0.304
KHM	2,298.052	21.503	0.190	0.660	0.014	0.136
KOR	3,136.828	23.748	0.094	0.553	0.080	0.273
LAO	2,276.618	21.653	0.203	0.618	0.024	0.155
LBN	2,949.307	27.402	0.033	0.329	0.291	0.346
LBR	2,413.147	22.696	0.160	0.569	0.057	0.214
LBY	2,819.511	27.920	0.028	0.303	0.325	0.344
LKA	2,393.628	22.659	0.150	0.588	0.049	0.213
LSO	2,443.539	24.497	0.198	0.386	0.196	0.219
MDA	2,744.517	25.819	0.085	0.402	0.218	0.295
MDG	2,063.263	21.149	0.213	0.665	0.009	0.112
MEX	3,153.162	28.223	0.019	0.280	0.340	0.361
MLI	2,380.311	22.546	0.159	0.586	0.048	0.207
MMR	2,415.821	22.317	0.161	0.608	0.037	0.193
MNG	2,343.994	25.452	0.067	0.437	0.178	0.318
MOR	3,236.670	25.612	0.063	0.428	0.186	0.322
MOZ	2,182.909	22.767	0.148	0.579	0.055	0.218
MRT	2,743.114	24.538	0.123	0.454	0.155	0.268
MWI	2,282.968	22.600	0.146	0.601	0.044	0.209
MYS	2,851.050	25.159	0.065	0.460	0.154	0.321
NAM	2,305.662	24.087	0.120	0.492	0.121	0.267
NER	2,282.292	21.648	0.186	0.649	0.018	0.147
NGA	2,843.210	23.495	0.114	0.552	0.078	0.256
NIC	2,280.903	26.809	0.040	0.362	0.254	0.344
NLD	3,192.617	25.646	0.055	0.430	0.182	0.333
NOR	3,386.605	26.449	0.034	0.383	0.221	0.361
NPL	2,360.639	20.800	0.252	0.642	0.008	0.098
NZL	3,082.753	27.696	0.022	0.308	0.303	0.367
OA0	2,505.402	24.408	0.098	0.489	0.128	0.285
OBN	3,809.645	26.396	0.051	0.384	0.234	0.331
OIO	2,648.193	24.659	0.111	0.458	0.155	0.277
OPO	2,750.342	30.384	0.010	0.188	0.484	0.318
OSA	3,114.718	23.359	0.108	0.574	0.066	0.252
PAK	2,344.949	22.935	0.140	0.573	0.060	0.227
PAN	2,509.418	27.142	0.031	0.342	0.271	0.356
PER	2,476.102	25.499	0.062	0.437	0.177	0.324
PHL	2,489.712	23.249	0.122	0.566	0.068	0.244

PNG	2,293.092	25.541	0.056	0.438	0.174	0.332
POL	3,436.490	26.383	0.055	0.384	0.235	0.326
PRT	3,525.476	26.542	0.043	0.377	0.237	0.343
PRY	2,683.933	25.849	0.064	0.413	0.204	0.320
RAP	3,592.176	28.496	0.014	0.260	0.357	0.369
ROU	2,822.336	25.544	0.069	0.429	0.186	0.315
RUS	3,221.116	26.791	0.047	0.363	0.259	0.331
RWA	2,130.883	22.441	0.156	0.602	0.041	0.200
SAU	3,017.263	28.743	0.020	0.261	0.378	0.341
SDN	2,317.891	22.949	0.157	0.547	0.071	0.225
SEN	2,349.171	23.225	0.154	0.524	0.087	0.235
SLB	2,488.824	28.184	0.021	0.285	0.339	0.355
SLE	2,123.274	23.406	0.123	0.548	0.079	0.250
SLV	2,564.537	27.286	0.029	0.334	0.280	0.357
SOM	1,641.926	22.451	0.178	0.567	0.053	0.202
SPP	3,223.271	26.992	0.038	0.352	0.266	0.344
SVK	2,877.605	26.789	0.042	0.363	0.255	0.340
SVN	3,187.477	27.145	0.037	0.344	0.276	0.343
SWE	3,074.641	25.847	0.044	0.422	0.185	0.349
SWZ	2,403.662	25.997	0.107	0.380	0.242	0.271
SYR	2,826.704	27.930	0.027	0.301	0.325	0.348
TCD	2,047.650	21.850	0.185	0.626	0.025	0.164
TGO	2,344.856	22.457	0.161	0.593	0.044	0.202
THA	2,818.676	23.763	0.112	0.530	0.094	0.265
TJK	2,247.631	23.950	0.115	0.509	0.109	0.267
TKM	2,969.780	25.046	0.076	0.460	0.156	0.308
TLS	2,135.318	21.193	0.254	0.589	0.022	0.135
TUN	3,225.562	26.658	0.053	0.369	0.254	0.324
TUR	3,586.570	27.563	0.033	0.322	0.303	0.342
TZA	2,238.515	22.950	0.131	0.585	0.055	0.229
UGA	2,413.965	22.550	0.152	0.596	0.045	0.207
UKP	3,357.533	27.297	0.025	0.331	0.277	0.367
UKR	2,782.169	26.031	0.060	0.403	0.214	0.323
URY	2,899.434	26.603	0.045	0.373	0.243	0.339
USA	3,725.186	28.449	0.016	0.266	0.355	0.363
UZB	2,580.100	25.501	0.069	0.432	0.183	0.315
VEN	2,552.055	27.949	0.020	0.294	0.321	0.366
VNM	2,565.323	21.151	0.209	0.672	0.008	0.110
VUT	2,807.039	27.788	0.025	0.306	0.313	0.355
YEM	2,044.273	25.293	0.083	0.437	0.179	0.301
ZAF	3,014.589	28.387	0.024	0.279	0.355	0.342
ZMB	1,932.330	22.002	0.198	0.585	0.038	0.178
ZWE	2,062.104	23.468	0.140	0.521	0.093	0.246

Table A4.2: Weight distribution estimated for the reference scenario without climate change in 2050, including food availability (kcal/cap/day), mean BMI (kg/m²), and the prevalence of underweight (BMI<18.5), normal weight (18.5<BMI<25), overweight (25<BMI<30), and obesity (BMI>30). See Appendix A7 for details on the regional aggregation.

Region	kcal/day	mean BMI	underweight	normal	obese	overweight
Global	3,106.920	24.564	0.086	0.504	0.136	0.274
HIC	3,433.591	26.814	0.043	0.363	0.258	0.336
AFR_LMIC	2,878.687	24.133	0.089	0.531	0.105	0.274
AMR_LMIC	3,051.496	27.159	0.034	0.342	0.275	0.349
EMR_LMIC	2,932.193	25.614	0.076	0.429	0.198	0.298
EUR_LMIC	3,256.108	26.786	0.046	0.363	0.258	0.332
SEA_LMIC	2,856.917	22.599	0.126	0.635	0.036	0.203
WPR_LMIC	3,512.785	23.718	0.099	0.553	0.083	0.265
AFG	2,707.125	21.641	0.214	0.601	0.027	0.157
AGO	2,414.308	23.205	0.153	0.528	0.084	0.234
ALB	3,137.648	26.777	0.041	0.364	0.252	0.343
ARG	3,312.530	27.900	0.027	0.303	0.323	0.346
ARM	3,130.366	27.455	0.041	0.329	0.301	0.329
AUS	3,180.132	27.422	0.026	0.325	0.287	0.363
AUT	3,725.637	25.818	0.061	0.416	0.200	0.324
AZE	3,086.018	26.801	0.048	0.362	0.260	0.330
BDI	2,911.192	23.982	0.088	0.538	0.091	0.283
BEN	2,878.247	24.146	0.091	0.519	0.104	0.286
BFA	3,002.857	22.366	0.138	0.640	0.029	0.192
BGD	2,782.031	21.310	0.196	0.674	0.010	0.120
BGR	3,062.887	26.771	0.042	0.364	0.254	0.340
BLR	2,881.158	26.577	0.050	0.374	0.245	0.331
BLT	3,805.255	26.259	0.059	0.389	0.230	0.321
BLX	3,748.324	26.049	0.053	0.405	0.209	0.333
BLZ	2,833.549	29.125	0.013	0.234	0.402	0.351
BOL	2,586.652	27.431	0.035	0.329	0.295	0.341
BRA	3,312.727	26.322	0.044	0.390	0.222	0.344
BTN	2,616.857	24.313	0.076	0.521	0.104	0.300
BWA	2,602.637	25.757	0.096	0.399	0.220	0.285
CAF	2,892.260	24.878	0.061	0.486	0.130	0.323
CAN	3,436.009	27.133	0.028	0.341	0.267	0.363
CHL	3,080.272	28.088	0.021	0.289	0.332	0.358
CHM	3,696.052	23.744	0.096	0.551	0.082	0.271
CHP	3,395.444	25.238	0.072	0.449	0.166	0.313
CIV	3,083.926	24.269	0.085	0.515	0.108	0.292
CMR	2,757.166	25.845	0.052	0.418	0.194	0.336
COD	2,329.237	23.141	0.100	0.609	0.048	0.242
COG	2,840.425	24.508	0.076	0.503	0.117	0.303
COL	2,866.867	26.210	0.051	0.395	0.220	0.334
CRB	3,220.390	27.844	0.031	0.308	0.321	0.341

CRI	3,084.976	27.422	0.028	0.326	0.289	0.356
CUB	2,731.581	27.078	0.038	0.347	0.272	0.342
CYP	2,487.433	26.560	0.053	0.374	0.247	0.326
CZE	3,524.977	27.600	0.038	0.322	0.309	0.331
DEU	3,523.643	26.455	0.045	0.382	0.232	0.341
DJI	2,586.010	25.425	0.073	0.435	0.181	0.311
DNK	3,344.449	25.740	0.050	0.426	0.184	0.339
DOM	2,699.604	27.238	0.033	0.338	0.280	0.349
DZA	3,181.067	25.847	0.061	0.414	0.202	0.323
ECU	2,439.139	27.265	0.031	0.336	0.280	0.353
EGY	3,554.289	28.969	0.017	0.248	0.392	0.344
ERI	2,269.600	22.825	0.107	0.635	0.036	0.221
ETH	2,598.601	22.085	0.143	0.667	0.020	0.170
FJI	3,746.224	29.500	0.014	0.224	0.427	0.335
FNP	3,165.777	26.250	0.047	0.394	0.219	0.340
FRP	3,470.045	25.283	0.069	0.448	0.167	0.316
GAB	2,994.513	25.974	0.057	0.408	0.207	0.328
GEO	3,466.304	27.329	0.038	0.335	0.290	0.337
GHA	3,131.944	24.541	0.079	0.498	0.122	0.302
GIN	3,319.370	24.349	0.072	0.521	0.103	0.303
GMB	2,947.676	24.832	0.093	0.461	0.154	0.292
GNB	2,753.077	23.398	0.134	0.536	0.085	0.246
GNQ	2,420.790	23.624	0.141	0.506	0.104	0.249
GRC	3,698.087	25.835	0.056	0.417	0.196	0.330
GSA	2,814.269	26.525	0.062	0.374	0.251	0.313
GTM	2,477.816	27.371	0.031	0.330	0.288	0.351
HND	2,940.335	27.109	0.035	0.345	0.272	0.347
HRV	3,153.283	26.216	0.058	0.393	0.226	0.323
HTI	2,264.499	25.730	0.048	0.428	0.181	0.343
HUN	3,593.332	26.870	0.046	0.359	0.263	0.332
IDN	3,113.117	23.810	0.092	0.549	0.083	0.276
IND	2,816.749	22.451	0.125	0.652	0.027	0.196
IRL	3,449.952	27.256	0.026	0.334	0.275	0.365
IRN	3,230.436	26.551	0.044	0.376	0.239	0.341
IRQ	3,247.910	28.229	0.020	0.281	0.341	0.358
ISL	3,351.063	26.874	0.035	0.358	0.254	0.353
ISR	3,875.938	27.553	0.031	0.321	0.301	0.348
ITP	3,774.865	25.694	0.057	0.426	0.186	0.331
JAM	3,070.686	27.757	0.039	0.315	0.320	0.326
JOR	3,645.939	29.277	0.017	0.236	0.412	0.335
JPN	2,761.541	22.660	0.134	0.612	0.042	0.212
KAZ	3,204.642	27.373	0.040	0.333	0.295	0.332
KEN	2,879.523	24.938	0.061	0.480	0.135	0.323
KGZ	3,195.221	26.380	0.056	0.384	0.236	0.324
KHM	2,507.912	22.141	0.144	0.659	0.022	0.175

KOR	3,317.767	24.038	0.083	0.539	0.091	0.288
LAO	2,430.677	22.140	0.169	0.617	0.032	0.182
LBN	3,237.990	28.023	0.025	0.296	0.331	0.348
LBR	2,880.931	23.964	0.100	0.526	0.099	0.276
LBY	3,039.940	28.486	0.022	0.274	0.361	0.342
LKA	2,622.342	23.338	0.115	0.567	0.069	0.250
LSO	2,757.836	25.441	0.163	0.369	0.235	0.233
MDA	3,228.035	26.922	0.060	0.354	0.276	0.310
MDG	2,516.018	22.649	0.107	0.657	0.028	0.208
MEX	3,224.335	28.364	0.018	0.272	0.350	0.360
MLI	2,677.022	23.413	0.114	0.560	0.073	0.253
MMR	2,683.389	23.077	0.119	0.589	0.056	0.237
MNG	3,481.703	28.318	0.021	0.279	0.349	0.351
MOR	3,707.639	26.198	0.050	0.396	0.218	0.335
MOZ	2,677.191	24.363	0.078	0.514	0.109	0.299
MRT	3,314.221	25.731	0.085	0.408	0.211	0.296
MWI	2,466.631	23.198	0.114	0.582	0.060	0.243
MYS	3,376.694	26.186	0.042	0.399	0.209	0.349
NAM	2,920.079	25.923	0.063	0.408	0.209	0.320
NER	2,965.293	23.476	0.081	0.600	0.055	0.264
NGA	3,233.595	24.261	0.084	0.516	0.107	0.293
NIC	2,714.033	28.365	0.021	0.277	0.352	0.350
NLD	3,207.693	25.673	0.055	0.429	0.183	0.333
NOR	3,325.685	26.357	0.036	0.389	0.216	0.359
NPL	2,899.462	22.164	0.142	0.659	0.022	0.177
NZL	3,233.707	28.001	0.019	0.290	0.324	0.368
OAO	2,818.539	25.301	0.071	0.445	0.170	0.314
OBN	3,915.727	26.449	0.050	0.381	0.237	0.332
OIO	2,785.324	25.033	0.098	0.443	0.172	0.287
OPO	2,886.749	30.804	0.009	0.171	0.511	0.309
OSA	3,100.348	23.334	0.109	0.575	0.065	0.251
PAK	2,677.749	23.940	0.095	0.534	0.093	0.278
PAN	2,771.974	27.986	0.022	0.294	0.325	0.359
PER	2,691.282	26.176	0.047	0.398	0.214	0.340
PHL	2,673.562	23.777	0.099	0.544	0.086	0.271
PNG	3,170.018	28.108	0.018	0.284	0.331	0.366
POL	3,613.968	26.590	0.051	0.373	0.247	0.329
PRT	3,638.748	26.662	0.041	0.370	0.244	0.345
PRY	2,904.583	26.442	0.051	0.381	0.237	0.331
RAP	3,742.360	28.639	0.013	0.252	0.367	0.368
ROU	3,004.479	25.978	0.059	0.407	0.209	0.325
RUS	3,402.141	27.085	0.042	0.347	0.276	0.334
RWA	3,098.934	25.209	0.047	0.469	0.141	0.343
SAU	3,145.813	29.035	0.018	0.247	0.397	0.338
SDN	2,641.594	23.950	0.110	0.514	0.106	0.270

SEN	2,753.128	24.429	0.103	0.483	0.133	0.282
SLB	3,026.394	29.842	0.010	0.202	0.450	0.337
SLE	2,415.567	24.479	0.081	0.500	0.120	0.299
SLV	2,715.097	27.770	0.024	0.306	0.311	0.359
SOM	2,971.678	27.497	0.024	0.319	0.290	0.367
SPP	3,183.723	26.919	0.039	0.356	0.262	0.343
SVK	3,004.414	27.097	0.038	0.346	0.273	0.343
SVN	3,313.082	27.367	0.034	0.331	0.290	0.345
SWE	3,098.274	25.895	0.043	0.419	0.188	0.350
SWZ	2,823.338	27.332	0.074	0.333	0.309	0.284
SYR	3,355.548	29.106	0.016	0.242	0.401	0.341
TCD	2,547.272	23.557	0.090	0.579	0.065	0.266
TGO	2,826.957	23.817	0.094	0.547	0.085	0.275
THA	3,173.737	24.496	0.084	0.496	0.123	0.297
TJK	2,644.186	25.270	0.071	0.447	0.168	0.314
TKM	3,363.641	25.764	0.057	0.421	0.193	0.329
TLS	2,669.442	22.837	0.141	0.582	0.055	0.222
TUN	3,632.475	27.220	0.043	0.341	0.286	0.330
TUR	3,628.229	27.607	0.032	0.319	0.306	0.342
TZA	2,748.297	24.533	0.067	0.510	0.111	0.312
UGA	2,961.830	23.985	0.085	0.542	0.089	0.285
UKP	3,412.285	27.378	0.024	0.326	0.282	0.367
UKR	3,013.545	26.602	0.048	0.373	0.246	0.333
URY	3,105.435	27.074	0.037	0.347	0.271	0.344
USA	3,608.789	28.339	0.017	0.272	0.347	0.364
UZB	3,021.062	26.678	0.044	0.369	0.248	0.339
VEN	2,661.363	28.317	0.017	0.273	0.346	0.364
VNM	2,840.574	21.807	0.156	0.681	0.014	0.149
VUT	3,511.302	29.247	0.013	0.230	0.410	0.347
YEM	2,230.944	26.096	0.062	0.398	0.221	0.319
ZAF	3,529.134	29.330	0.016	0.234	0.416	0.334
ZMB	2,913.071	25.214	0.056	0.462	0.150	0.331
ZWE	2,761.390	25.869	0.059	0.414	0.201	0.326

Table A4.3: Average weight distribution estimated for climate change scenarios in 2050, including food availability (kcal/cap/day), mean BMI (kg/m²), and the prevalence of underweight (BMI<18.5), normal weight (18.5<BMI<25), overweight (25<BMI<30), and obesity (BMI>30). See Appendix A7 for details on the regional aggregation.

Region	kcal/day	mean BMI	underweight	normal	obese	overweight
Global	3,008.334	24.369	0.095	0.511	0.129	0.265
HIC	3,372.514	26.729	0.045	0.367	0.254	0.335
AFR_LMIC	2,756.536	23.841	0.101	0.544	0.095	0.260
AMR_LMIC	2,979.039	26.996	0.037	0.351	0.265	0.347
EMR_LMIC	2,855.424	25.444	0.081	0.435	0.190	0.293
EUR_LMIC	3,198.842	26.681	0.048	0.369	0.252	0.331
SEA_LMIC	2,740.550	22.334	0.142	0.640	0.031	0.187
WPR_LMIC	3,401.541	23.590	0.105	0.557	0.079	0.258
AFG	2,603.710	21.385	0.234	0.599	0.023	0.144
AGO	2,301.279	22.834	0.173	0.536	0.073	0.218
ALB	3,079.460	26.659	0.043	0.370	0.245	0.342
ARG	3,259.228	27.809	0.028	0.308	0.317	0.346
ARM	3,061.184	27.310	0.043	0.336	0.292	0.328
AUS	3,124.020	27.310	0.027	0.331	0.280	0.362
AUT	3,662.037	25.766	0.062	0.419	0.197	0.322
AZE	3,014.498	26.647	0.051	0.370	0.251	0.328
BDI	2,773.836	23.661	0.101	0.553	0.079	0.267
BEN	2,707.567	23.728	0.107	0.539	0.088	0.266
BFA	2,912.107	22.184	0.150	0.643	0.026	0.181
BGD	2,641.667	20.984	0.225	0.665	0.008	0.102
BGR	3,014.495	26.666	0.044	0.370	0.247	0.339
BLR	2,838.406	26.467	0.052	0.380	0.239	0.329
BLT	3,786.180	26.247	0.060	0.390	0.230	0.321
BLX	3,716.807	26.026	0.053	0.406	0.208	0.333
BLZ	2,762.356	28.916	0.014	0.245	0.387	0.353
BOL	2,516.782	27.195	0.038	0.341	0.281	0.339
BRA	3,240.580	26.204	0.046	0.397	0.215	0.342
BTN	2,506.436	23.985	0.087	0.538	0.091	0.284
BWA	2,506.698	25.455	0.105	0.411	0.205	0.279
CAF	2,757.180	24.545	0.070	0.506	0.115	0.309
CAN	3,371.179	27.040	0.029	0.347	0.261	0.362
CHL	3,017.499	27.947	0.022	0.296	0.323	0.359
CHM	3,582.217	23.649	0.100	0.555	0.078	0.266
CHP	3,340.717	25.161	0.074	0.453	0.163	0.311
CIV	2,925.556	23.945	0.096	0.531	0.095	0.277
CMR	2,624.798	25.466	0.061	0.440	0.173	0.326
COD	2,231.305	22.799	0.117	0.622	0.040	0.220
COG	2,698.107	24.145	0.088	0.522	0.102	0.287
COL	2,799.614	26.037	0.055	0.405	0.210	0.330
CRB	3,211.960	27.828	0.031	0.308	0.320	0.341

CRI	3,008.371	27.253	0.030	0.336	0.278	0.355
CUB	2,646.762	26.823	0.042	0.361	0.257	0.339
CYP	2,446.420	26.417	0.056	0.382	0.238	0.324
CZE	3,474.722	27.536	0.039	0.325	0.305	0.331
DEU	3,465.907	26.385	0.046	0.386	0.228	0.340
DJI	2,478.944	25.083	0.083	0.451	0.164	0.301
DNK	3,290.507	25.657	0.052	0.431	0.179	0.337
DOM	2,629.289	27.021	0.036	0.350	0.267	0.347
DZA	3,113.659	25.721	0.064	0.420	0.195	0.320
ECU	2,377.236	27.032	0.034	0.349	0.266	0.351
EGY	3,439.596	28.818	0.018	0.255	0.382	0.345
ERI	2,198.901	22.573	0.121	0.644	0.031	0.204
ETH	2,525.782	21.886	0.157	0.669	0.017	0.157
FJI	3,627.226	29.389	0.015	0.229	0.420	0.336
FNP	3,115.141	26.151	0.049	0.400	0.214	0.338
FRP	3,410.642	25.208	0.071	0.452	0.163	0.314
GAB	2,853.491	25.640	0.064	0.426	0.190	0.320
GEO	3,402.069	27.241	0.040	0.339	0.285	0.336
GHA	2,969.647	24.220	0.090	0.514	0.108	0.288
GIN	3,128.097	24.036	0.083	0.539	0.091	0.288
GMB	2,828.785	24.549	0.102	0.474	0.141	0.283
GNB	2,588.984	22.963	0.155	0.548	0.071	0.226
GNQ	2,294.714	23.196	0.161	0.518	0.089	0.232
GRC	3,635.301	25.781	0.057	0.420	0.194	0.329
GSA	2,766.360	26.394	0.065	0.380	0.244	0.312
GTM	2,410.201	27.127	0.034	0.344	0.273	0.349
HND	2,868.705	26.932	0.038	0.355	0.261	0.346
HRV	3,108.022	26.128	0.060	0.397	0.221	0.322
HTI	2,195.821	25.455	0.054	0.445	0.166	0.335
HUN	3,544.223	26.817	0.047	0.361	0.260	0.332
IDN	2,958.390	23.510	0.105	0.563	0.073	0.260
IND	2,708.079	22.195	0.140	0.658	0.023	0.179
IRL	3,391.759	27.174	0.027	0.339	0.269	0.365
IRN	3,146.162	26.396	0.047	0.385	0.230	0.339
IRQ	3,150.363	28.039	0.021	0.291	0.329	0.358
ISL	3,300.591	26.794	0.036	0.362	0.249	0.352
ISR	3,778.313	27.495	0.031	0.324	0.297	0.347
ITP	3,735.681	25.667	0.057	0.428	0.185	0.330
JAM	2,997.507	27.591	0.041	0.323	0.310	0.325
JOR	3,566.894	29.190	0.017	0.240	0.407	0.336
JPN	2,701.615	22.514	0.143	0.615	0.038	0.204
KAZ	3,137.640	27.244	0.042	0.340	0.287	0.331
KEN	2,746.762	24.614	0.071	0.499	0.120	0.310
KGZ	3,126.617	26.251	0.059	0.390	0.229	0.322
KHM	2,385.770	21.779	0.169	0.661	0.017	0.152

KOR	3,247.010	23.932	0.087	0.544	0.087	0.282
LAO	2,312.454	21.770	0.195	0.619	0.026	0.161
LBN	3,170.715	27.895	0.027	0.303	0.322	0.348
LBR	2,703.794	23.531	0.118	0.544	0.083	0.256
LBY	2,976.762	28.336	0.024	0.281	0.352	0.343
LKA	2,512.824	23.025	0.130	0.578	0.059	0.233
LSO	2,624.721	25.075	0.176	0.376	0.220	0.228
MDA	3,174.837	26.825	0.062	0.359	0.271	0.309
MDG	2,315.432	22.030	0.144	0.672	0.018	0.166
MEX	3,139.737	28.199	0.019	0.281	0.339	0.361
MLI	2,560.522	23.089	0.129	0.572	0.063	0.236
MMR	2,564.709	22.755	0.136	0.599	0.047	0.218
MNG	3,407.848	28.215	0.022	0.284	0.342	0.352
MOR	3,637.094	26.138	0.052	0.399	0.215	0.334
MOZ	2,526.864	23.931	0.094	0.536	0.092	0.279
MRT	3,190.408	25.526	0.090	0.416	0.201	0.292
MWI	2,339.197	22.798	0.135	0.595	0.049	0.221
MYS	3,300.369	26.070	0.044	0.406	0.203	0.347
NAM	2,813.869	25.660	0.069	0.422	0.195	0.315
NER	2,873.653	23.270	0.090	0.611	0.049	0.251
NGA	3,095.978	24.021	0.093	0.528	0.097	0.281
NIC	2,629.341	28.098	0.023	0.291	0.335	0.351
NLD	3,156.621	25.581	0.057	0.434	0.178	0.331
NOR	3,267.871	26.264	0.037	0.395	0.210	0.357
NPL	2,774.081	21.893	0.160	0.662	0.019	0.159
NZL	3,175.783	27.890	0.020	0.296	0.316	0.368
OAO	2,790.378	25.229	0.073	0.449	0.166	0.312
OBN	3,894.018	26.440	0.050	0.382	0.236	0.332
OIO	2,761.079	24.970	0.100	0.445	0.169	0.286
OPO	2,866.541	30.745	0.009	0.174	0.507	0.311
OSA	3,078.170	23.293	0.111	0.577	0.064	0.249
PAK	2,618.338	23.777	0.101	0.542	0.087	0.270
PAN	2,690.248	27.741	0.024	0.308	0.309	0.359
PER	2,604.714	25.916	0.053	0.413	0.199	0.335
PHL	2,577.985	23.511	0.110	0.556	0.076	0.258
PNG	3,092.304	27.944	0.020	0.294	0.320	0.366
POL	3,564.332	26.538	0.052	0.376	0.244	0.328
PRT	3,562.047	26.584	0.042	0.375	0.239	0.344
PRY	2,836.179	26.271	0.054	0.390	0.227	0.328
RAP	3,633.230	28.540	0.014	0.258	0.360	0.369
ROU	2,955.780	25.869	0.061	0.413	0.203	0.323
RUS	3,343.155	26.998	0.044	0.352	0.271	0.333
RWA	2,965.556	24.933	0.054	0.487	0.127	0.332
SAU	3,070.149	28.869	0.019	0.255	0.386	0.340
SDN	2,580.594	23.776	0.118	0.521	0.099	0.263

SEN	2,594.740	23.993	0.119	0.500	0.115	0.266
SLB	2,930.027	29.592	0.011	0.214	0.433	0.342
SLE	2,267.776	23.957	0.100	0.526	0.098	0.276
SLV	2,645.514	27.557	0.026	0.318	0.297	0.358
SOM	2,905.087	27.334	0.025	0.329	0.280	0.366
SPP	3,125.722	26.807	0.041	0.362	0.255	0.342
SVK	2,959.067	26.991	0.039	0.352	0.267	0.342
SVN	3,262.594	27.283	0.035	0.336	0.285	0.345
SWE	3,046.829	25.789	0.045	0.425	0.182	0.347
SWZ	2,696.766	26.975	0.082	0.346	0.290	0.282
SYR	3,284.065	28.983	0.017	0.247	0.393	0.342
TCD	2,464.367	23.302	0.101	0.591	0.057	0.251
TGO	2,664.886	23.411	0.111	0.565	0.071	0.254
THA	3,094.619	24.353	0.089	0.503	0.117	0.291
TJK	2,582.287	25.086	0.076	0.457	0.159	0.309
TKM	3,285.401	25.646	0.060	0.428	0.186	0.326
TLS	2,570.095	22.572	0.156	0.589	0.048	0.208
TUN	3,557.115	27.142	0.044	0.345	0.282	0.329
TUR	3,550.512	27.523	0.033	0.324	0.301	0.342
TZA	2,614.599	24.170	0.079	0.531	0.096	0.294
UGA	2,851.265	23.739	0.094	0.554	0.080	0.272
UKP	3,351.729	27.288	0.025	0.332	0.276	0.367
UKR	2,963.393	26.489	0.050	0.379	0.240	0.331
URY	3,037.813	26.931	0.039	0.355	0.263	0.343
USA	3,545.683	28.267	0.017	0.276	0.342	0.364
UZB	2,948.452	26.512	0.047	0.378	0.238	0.336
VEN	2,599.386	28.114	0.018	0.284	0.332	0.365
VNM	2,720.226	21.536	0.176	0.680	0.012	0.132
VUT	3,395.074	29.079	0.014	0.238	0.399	0.349
YEM	2,182.585	25.897	0.067	0.408	0.210	0.315
ZAF	3,427.580	29.193	0.017	0.240	0.407	0.336
ZMB	2,754.758	24.831	0.066	0.485	0.132	0.317
ZWE	2,651.872	25.567	0.066	0.430	0.185	0.319

Appendix A5: Description of comparative risk assessment framework

We estimated the mortality and disease burden attributable to dietary and weight-related risk factors by calculating population attributable fractions (PAFs) using the general formula:^{46,47}

$$PAF = \frac{\int RR(x)P(x)dx - \int RR(x)P'(x)dx}{\int RR(x)P(x)dx} \quad (26)$$

where $RR(x)$ is the relative risk of disease for risk factor level x , $P(x)$ is the number of people in the population with risk factor level x in the baseline scenario, and $P'(x)$ is the number of people in the population with risk factor level x in the counterfactual scenario.

PAFs are defined as the proportions of disease cases that would be avoided when the risk exposure was changed from the counterfactual situation to the baseline situation, whilst the distribution of other risk factors in the population remain unchanged.⁴⁸ The combined burden attributable to independent risk factors was calculated by multiplying the PAF complements and taking its complement:^{47,49}

$$PAF_{TOT} = 1 - \prod_i (1 - PAF_i), \quad i = \{diet, weight\} \quad (27)$$

where PAF_{TOT} is the final PAF after all PAFs for risk factors i have been combined.

We reported the health impacts of changes in risk exposure in terms of changes in the number of deaths. The number of avoided deaths due to the change in risk exposure of risk i , $\Delta deaths_i$, was calculated by multiplying the associated PAF by disease-specific death rates, DR , and by the number of people alive within a population, P :

$$\Delta deaths_i(r, a, d) = PAF_i(r, d) \cdot DR(r, a, d) \cdot P(r, a) \quad (28)$$

where PAFs are differentiated by region r and disease/cause of death d ; the death rates are differentiated by region, age group a , and disease; the population groups are differentiated by region and age group; and the change in the number of deaths is differentiated by region, age group and disease.

We included two dietary risk factors (fruit and vegetable consumption and red-meat consumption), and four levels of weight-related risks (underweight, normal weight, overweight, obesity). We treated each risk factor as discrete for ease of analysis. For discrete risk factors with i levels, Equation (26) becomes:⁴⁶

$$PAF = \frac{\sum P_i RR_i - \sum P'_i RR_i}{\sum P_i RR_i} = 1 - \frac{\sum P'_i RR_i}{\sum P_i RR_i} \quad (29)$$

The following summarizes the specific expressions of the equations above as used in the comparative risk assessment.

Dietary risk factors

For the dietary risk factors, it was assumed that the whole population of a region is subject to the dietary risks associated with its regional consumption level c measured in g/cap/day, and that risks begin increasing at zero consumption and are unbounded. We adopted standard serving sizes of 80g for fruit and vegetables (s_{FV}) and 100g for red meat (s_{meat}). Taking into account regional consumption levels c , the relative risk associated with the consumption-based risk factor $f = \{FV, meat\}$ was calculated by raising the risk factor to the power of the consumption level over the serving size, i.e. $RR_{r,f} = RR_f^{c_r/s_f}$. The associated PAF for region r , risk factor f , and disease/cause of death d was expressed as:

$$PAF_{r,f,d}^{diet} = \frac{RR_{f,d}^{c_{ref,r/sf}} - RR_{f,d}^{c_{scn,r/sf}}}{RR_{f,d}^{c_{ref,r/sf}}} = 1 - \frac{RR_{f,d}^{c_{scn,r/sf}}}{RR_{f,d}^{c_{ref,r/sf}}}, \quad f = \{FV, meat\} \quad (30)$$

where c_{ref} denotes the consumption level in the baseline scenario, and c_{scn} the consumption level in the counterfactual scenario.

We calculated the combined disease and mortality burden of changes in dietary risk factors by using equation (27):

$$\begin{aligned} PAF_{r,d}^{diet} &= 1 - \prod_f (1 - PAF_{r,f,d}^{diet}) \\ &= PAF_{r,f=FV,d}^{diet} + PAF_{r,f=meat,d}^{diet} - PAF_{r,f=FV,d}^{diet} PAF_{r,f=meat,d}^{diet} \end{aligned} \quad (31)$$

Weight-related risk factors

The weight-related PAFs accounted for the weight status of different population fractions and the associated risks. Following equation (29), they were expressed as:

$$PAF_{r,d}^{weight} = \frac{\sum_w p_{r,w}^{ref} RR_{w,d} - \sum_w p_{r,w}^{scn} RR_{w,d}}{\sum_w p_{r,w}^{ref} RR_{w,d}} = 1 - \frac{\sum_w p_{r,w}^{scn} RR_{w,d}}{\sum_w p_{r,w}^{ref} RR_{w,d}}, \quad (32)$$

$$w = \{underweight, normal, overweight, obese\}$$

where the relative risks RR are differentiated by disease d and weight category w ; and the population fractions p are differentiated by region and weight category; they are indexed by ref and scn for their levels in the baseline and counterfactual scenario, respectively.

The PAFs given by equation (32) account for the combined disease burden of all weight categories. We decomposed those combined PAFs, $PAF_{r,d}^{weight}$, into PAFs associated with single weight categories (e.g. overweight), PAF_{r,d,w_1}^{weight} , by using the same equation and assigning only the change in prevalence of that specific weight category to $p_{r,w}^{scn}$, whilst keeping all other population fractions associated with weight risks unchanged from the baseline scenario, and absorbing the change in population fractions from the selected category by the risk-neutral normal weight category:

$$\begin{aligned} PAF_{r,d,w_1}^{weight} &= PAF_{r,d}^{weight} \text{ with } p_{w=w_1}^{scn} = p'_{w_1}; p_{w=w_2}^{scn} = p_{w_2}; \\ p_{w=w_3}^{scn} &= p_{w_3}; p_{normal}^{scn} = p_{normal} + (1 - \sum_{w_i} p_{w_i}^{scn}) \end{aligned} \quad (33)$$

This was done successively for each weight category $w_1 \dots w_3$.

Changes in mortality

We calculated the number of disease-specific deaths that would be avoided when the risk exposure was changed from the counterfactual situation to the baseline situation by multiplying the PAFs differentiated by risk factor and disease by disease-specific death rates and population numbers:

$$\Delta deaths_{r,a,f,d} = PAF_{r,f,d} DR_{r,a,d} P_{r,a} \quad (34)$$

The number of avoided deaths was differentiated by region, age group, risk factor, and disease.

Appendix A6: Relative risk parameters

We used publically available data sources to parameterize the comparative risk analysis. 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 and older). We restricted the selection of relative risk parameters to meta-analyses and pooled prospective cohort studies. The diet and weight-related relative risk parameters were adopted from pooled analyses of prospective cohort studies,^{50,51} and from meta-analysis of prospective cohort and case-control studies.⁵²⁻⁵⁶ The cancer associations have been judged as probable or convincing by the World Cancer Research Fund,⁵⁶ and in each case a dose-response relationship was apparent and consistent evidence suggests plausible mechanisms. Table A6.1 provides an overview of the relative risk parameters adopted in this study, and the short reviews below detail the selection process.

Table A6.1: Relative risk parameters (mean and 95% confidence intervals in parenthesis)

Risk factor	Relative risk per cause of death			
	CHD	Stroke	Cancer	Other
FV consumption	0.96 (0.93-0.99)	0.95 (0.92-0.97)	0.93 (0.84-0.99)*	1.00
meat consumption	1.25 (1.21-1.29)	1.10 (1.05-1.15)	1.01 (1.00-1.05)*	1.00
underweight	0.67 (0.65-0.70)	1.03 (0.71-1.47)	1.11 (0.94-1.32)	1.75 (1.50-2.05)
normal weight	1.00	1.00	1.00	1.00
overweight	1.31 (1.24-1.39)	1.07 (0.73-1.59)	1.10 (1.04-1.17)	0.96 (0.89-1.03)
obese	1.78 (1.64-1.92)	1.55 (1.14-2.11)	1.40 (1.30-1.50)	1.33 (1.22-1.46)

* global average, actual RR is region-specific.

Weight-related risk parameters

Excess weight is an established risk factor for several causes of death, including ischaemic heart disease,^{57,58} stroke,⁵⁸⁻⁶⁰ and various cancers.^{56,61-63} Plausible biological explanations^{50,64,65} and the identification of mediating factors^{50,66} suggest that the association between body weight and mortality is not merely statistical association, but a causal link independent of other factors, such as diet and exercise.⁶⁷⁻⁷¹

We inferred the parameters describing relative mortality risk due to weight categories from two large, pooled analyses of prospective cohort studies.^{50,51} We concentrated on four broad causes of death: ischaemic/coronary heart disease, stroke, cancers, and all other causes. We adopted the relative risks for ischaemic heart disease and stroke from the Prospective Studies Collaboration,⁵⁰ which analysed the association between BMI and mortality among 900,000 persons in 57 prospective studies that were primarily designed to evaluate risk factors for cardiovascular disease; and we adopted the relative risks for cancer and all other causes from Berrington de Gonzalez and colleagues,⁵¹ who examined the relationship between BMI and mortality in a pooled analysis of 19 prospective studies which included 1.46 million adults and which were predominantly designed to study cancer.

From each study, we adopted the relative risk rates for lifelong non-smokers to minimize confounding and reverse causality, and, to increase comparability, we normalized the relative-risk schedule to the lowest risk which, in each case corresponded to a body-mass index (BMI) of 22.5-25. We then used the number of cause-specific deaths to aggregate the BMI intervals of 2.5 that have been used in the studies to the WHO classification of BMI ranges,⁷² i.e. BMI < 18.5: underweight; 18.5-24.9: normal range; 25-29.9: overweight; and 30-39.9: obesity.

Dietary risk parameters

Dietary risks have been the leading risk factors for death globally in 2010.⁴⁷ The Global Burden of Disease Study included 14 different components as dietary risks, such as not eating enough fruit, nuts and seeds, vegetables, whole grains, and omega-3s and eating too much salt and processed meat.⁴⁷ Dietary factors have been associated with the development of cardiovascular diseases, diabetes, and various cancers, and total mortality.^{47,73,74}

In this study, we focused on changes in the consumption of fruits, vegetables, and meat. Those categories constituted about two thirds of the total dietary risk in 2010 (excluding potential double counting, e.g. of fibre found in vegetables and sodium found in processed meat),⁴⁷ and country-level trends and data are available for most countries worldwide. We adopted relative-risk parameters for developing specific diseases from recent meta-analyses of existing studies.

Meat consumption

Meat consumption has been associated with increases in total mortality,⁷⁵ a greater incidence of cardiovascular diseases,⁵² and colorectal cancer.⁵⁶

Meat consumption and cardiovascular disease

The relative risks of coronary heart diseases due to meat consumption were adopted from Micha and colleagues⁵² (for an updated discussion, see a new contribution by Micha and others⁷⁶). Their comprehensive systematic review and meta-analysis of the relationship between meat consumption (processed, red, and total meat) and cardiovascular diseases (coronary heart disease (CHD), diabetes mellitus, and stroke) included 20 studies (17 prospective cohorts and 3 case-control studies) with 1,218,380 individuals from 10 countries. However, analyses of specific subcategories, e.g. total meat consumption and stroke, included significantly less studies. The results show positive associations between consumption of processed and total meat and the incidence of CHD, diabetes mellitus, and stroke.

Since the publication of Micha et al.⁵², updated reviews of the association between meat consumption and stroke have become available. We therefore only adopted the estimates for the association between meat consumption and coronary heart disease. We excluded the findings for diabetes mellitus, because we focused on mortality, and diabetes mellitus is not an immediate or leading cause of death. We adopted the findings for total meat. The final estimate adopted is as follows:

- Consumption of 100 g per day increases CHD risk by 25% (RR=1.25; 95% CI, 1.21 to 1.29). The estimate is based on data from 4 prospective cohort studies; one extremely positive finding from a case-control study was excluded in the estimate⁵².

The relative risk of stroke due to meat consumption was adopted from Chen et al.⁵³ which, for stroke, provided an updated meta-analysis of Micha et al.⁵² containing five large independent cohort studies (compared to two in Micha et al.⁵²). It should be noted that another recent meta-analysis, Kaluza et al.⁷⁷, produced very similar estimates. Chen et al.⁵³ found that consumption of red and/or processed meat increases the risk of stroke, in particular, ischemic stroke. Their dose–response analysis of the primary studies showed that the risk of stroke increased significantly by 10% for each 100 g per day increment in total meat consumption (RR=1.10; 95% CI, 1.05–1.15), by 13% for each 100 g per day increment in red meat consumption (RR=1.13; 95% CI, 1.03–1.23) and by 11% for each 50 g per day increment in processed meat consumption (RR=1.11; 95% CI, 1.02–1.20), with low study heterogeneity. We adopted the estimate for total meat consumption.

Meat consumption and cancer

The association between meat consumption and cancer was reviewed in the Second Expert Report "Food, Nutrition, Physical Activity, and the Prevention of Cancer: a Global Perspective" published in 2007 by the

World Cancer Research Fund together with the American Institute for Cancer Research.⁵⁶ The report is based on reviews and meta-analysis of over 7,000 scientific studies published on cancer prevention. It was the outcome of a 5-year project which involved a panel of 21 leading scientists and 9 research centres around the world.

With respect to meat, the report concluded that:⁵⁶ red and processed meats are convincing causes of colorectal cancer; there is substantial amount of evidence, with a dose-response relationship apparent from case-control studies (red meat) and cohort studies (processed meat); there is evidence (red meat) and strong evidence (processed meat) for plausible mechanisms operating in humans. The report also noted that there is limited evidence suggesting that red meat is a cause of cancers of the oesophagus, lung, pancreas and endometrium; and that processed meat is a cause of cancers of the oesophagus, lung, stomach and prostate.

Since the expert report was published in 2007, several meta-analyses of the association between meat consumption and different cancers have become available. The expert report was updated for colorectal cancer which preserved its main conclusions, but changed the numerical relative-risk value. One meta-analysis has become available,⁷⁸ which summarized the evidence from prospective studies of red and processed meat consumption and pancreatic cancer risk. It found a positive association for processed meat. In line with that, a WCRF update on pancreatic cancer found that the evidence for processed meat and pancreatic cancer is now stronger but remains limited.⁷⁹ Several other meta-analyses found that meat consumption is associated with increased risks of stomach/gastric cancer,^{80,81} and oesophageal cancer,⁸²⁻⁸⁵ but the associations became insignificant in most cases when restricted to prospective cohort studies.

We followed the conclusions of the expert report (and its updates) that highlighted a convincing causal link between meat consumption and colorectal cancer and adopted the following estimate:^{56,86}

- Consumption of 100 g/day of red and processed meat increases the risk of colorectal cancer by 16% (RR=1.16, CI=1.04-1.30).⁸⁶ We aggregated the estimate to region-specific relative risks for all cancers by weighing it by the ratio of regional deaths due to colorectal cancer to all cancer deaths in that region. Globally, this resulted in a relative risk of cancer of RR=1.01.

Fruit and vegetable consumption

The WHO stated that diets high in fruits and vegetables play an important role in the prevention of chronic diseases.⁸⁷ Most prospective studies have consistently shown lower all-cause mortality when comparing people with high and low fruit and vegetable consumption,⁸⁸⁻⁹² and findings from a large cohort study including 451,151 participants from 10 European countries have supported the evidence that fruit and vegetable consumption is associated with lower risk of all-cause and cause-specific mortality.⁹³

Fruit and vegetable consumption and cardiovascular disease

The relative risks of stroke and CHD due to fruit and vegetable consumption were adopted from Dauchet and colleagues.^{54,55} Dauchet et al.⁵⁵ conducted a meta-analysis for CHD (see He et al.⁹⁴ for a similar analysis). The analysis included nine prospective cohort studies that consisted of 91,379 men, 129,701 women, and 5,007 CHD events. Pooled relative risks showed that CHD was decreased by 4% [RR (95% CI): 0.96 (0.93-0.99)] for each additional portion per day of fruit and vegetable intake and by 7% [0.93 (0.89-0.96)] for fruit intake. We adopted the estimate for the aggregate of fruit and vegetable consumption, i.e. RR=0.96 (0.93-0.99).

Dauchet et al.⁵⁴ undertook a similar meta-analysis for stroke. The analysis included seven cohort studies with 90,513 men, 141,536 women, and 2,955 strokes. Pooled relative risks showed that the risk of stroke was decreased by 11% (RR 95% CI: 0.89 [0.85 to 0.93]) for each additional portion per day of fruit, by 5% (RR: 0.95 [0.92 to 0.97]) for fruit and vegetables, and by 3% (RR: 0.97 [0.92 to 1.02]) for vegetables. The study found that the association between fruit or fruit and vegetables and stroke was linear, suggesting a dose-response relationship. We adopted the estimate for the aggregate of fruit and vegetable consumption, i.e. RR=0.95 (0.92-0.97).

Fruit and vegetable consumption and cancer

The relative risks of various cancers due to fruit and vegetable consumption were adopted from the 2007 expert report of the World Cancer Research Fund and the American Institute for Cancer Research.⁵⁶ The expert report concluded that:

“[N]on-starchy vegetables and also fruits probably protect against cancers of the mouth, larynx, pharynx, oesophagus, and stomach, and that fruits also probably protect against lung cancer. The case that vegetables, fruits, and pulses (legumes) may be protective against cancers of some sites is supported by evidence on foods containing micronutrients found in these and other plant foods. Foods containing carotenoids probably protect against cancers of the mouth, pharynx, larynx, and lung; foods containing beta-carotene and also vitamin C probably protect against oesophageal cancer; foods containing selenium and also lycopene probably protect against prostate cancer; and foods containing folate probably protect against pancreatic cancer. [...] [It was also found that] foods containing dietary fibre, found in plant foods (particularly when in whole or relatively unprocessed forms), probably protect against colorectal cancer.”

We adopted the following relative risk parameters for which the expert report indicated a substantial amount of consistent evidence for plausible mechanisms and a dose-response relationship:

Cancers of the mouth, pharynx, and larynx:

- Consumption of non-starchy vegetables reduces the risk of cancers of the mouth, pharynx, and larynx by 28% per 50-g serving per day (RR=0.72; 95% CI: 0.63-0.82).
- Consumption of fruits reduces the risk of cancers of the mouth, pharynx, and larynx by 28% per 100-g serving per day (95% CI: 0.59-0.87).
- We adopted the simple average of vegetable and fruit consumption for the relative risk of cancers of the mouth, pharynx, and larynx, i.e. RR=0.72 (0.61-0.85).

Oesophageal cancer:

- Consumption of raw vegetables reduces the risk of oesophageal cancer by 31% per 50-g serving per day (RR=0.69; 95% CI: 0.58-0.83).
- Consumption of fruits reduces the risk of oesophageal cancer by 44% per 100-g serving per day (RR=0.56; 95% CI: 0.42-0.74).
- We adopted the simple average of vegetable and fruit consumption for the relative risk of oesophageal cancer, i.e. RR=0.63 (0.50-0.79).

Stomach cancer:

- Consumption of non-starchy vegetables reduces the risk of stomach cancer by 30% per 100-g serving per day (RR=0.70; 95% CI: 0.62-0.79).
[Estimates of green-yellow vegetables yield RR=0.59 (0.46-0.75) per 100 g/d; green, leafy vegetables yield RR=0.43 (0.24-0.77) per 50 g/d; and raw vegetables yield RR=0.5 (0.38-0.65) per 100 g/d]
- Consumption of fruits reduces the risk of stomach cancer by 33% per 100-g serving per day (RR=0.67; 95% CI: 0.59-0.76).
- We adopted the simple average of vegetable and fruit consumption for the relative risk of stomach cancer, i.e. RR=0.69.

Lung cancer:

- Consumption of fruits reduces the risk of lung cancer by 6% per 80-g serving per day (RR=0.94; 95% CI: 0.90-0.97).
- We adopted the simple average of vegetable and fruit consumption for the relative risk of lung cancer (assuming no effect of vegetable consumption, RR=1), i.e. RR=0.97.

Overall relative risk:

- We aggregated the cause-specific relative-risk estimates to region-specific all-cancer estimates by weighing each risk by the ratio of regional deaths due to the specific cancer divided by all cancer deaths in that region. Globally, this yielded an aggregate all-cancer risk of RR=0.93.

Appendix A7: Regional aggregation

Our analysis yielded results for 155 regions. We aggregated the results for individual countries into results for regional aggregates to provide an overview and ease the presentation of results. For that purpose, we used the WHO-World Bank classification. WHO Member States were classified according to the World Bank income category for the year 2011 (World Bank list of economies, July 2012) and WHO region:

HIC: high-income countries;
AFR_LMIC: low and middle-income countries of Africa;
AMR_LMIC: low and middle-income countries of America;
EMR_LMIC: low and middle-income countries of the Eastern Mediterranean;
EUR_LMIC: low and middle income countries of Europe;
SEA_LMIC: low and middle-income countries of South-East Asia;
WPR_LMIC: low and middle-income countries of the Western Pacific.

The assignment of countries to the regional aggregates is detailed below.

HIC High-income countries

* *AMR American Region:*

CAN Canada

CRB Other Caribbean

USA United States of America

* *EMR Eastern-Mediterranean Region:*

RAP Rest of Arab Peninsula

SAU Saudi Arabia

* *EUR European Region:*

AUT Austria

BLX Belgium and Luxembourg

CHP Switzerland

CYP Cyprus

CZE Czech Republic

DEU Germany

DNK Denmark

FNP Finland

FRP France

GRC Greece

HRV Croatia

HUN Hungary

IRL Ireland

ISL Iceland

ISR Israel

ITP Italy

NLD Netherlands
NOR Norway
POL Poland
PRT Portugal
SPP Spain
SVK Slovakia
SVN Slovenia
SWE Sweden
UKP United Kingdom

* *WPR Western Pacific Region:*

AUS Australia
JPN Japan
KOR Republic of Korea
NZL New Zealand
OSA Other Southeast Asia

(Note: GNQ, Equatorial Guinea, was re-classified as UMC in accordance with WHO mortality projections)

AFR_LMIC Low and middle-income Africa

BWA Botswana
DZA Algeria
GAB Gabon
GNQ Equatorial Guinea
NAM Namibia
ZAF South Africa
AGO Angola
CIV Côte d'Ivoire
CMR Cameroon
LSO Lesotho
NGA Nigeria
OAO Other Atlantic Ocean
OIO Other Indian Ocean
SWZ Swaziland
BDI Burundi
BEN Benin
BFA Burkina Faso
CAF Central African Republic
COD Democratic Republic of the Congo
COG Congo

ERI	Eritrea
ETH	Ethiopia
GHA	Ghana
GIN	Guinea
GMB	Gambia
GNB	Guinea-Bissau
KEN	Kenya
LBR	Liberia
MDG	Madagascar
MLI	Mali
MOZ	Mozambique
MRT	Mauritania
MWI	Malawi
NER	Niger
RWA	Rwanda
SEN	Senegal
SLE	Sierra Leone
TCD	Chad
TGO	Togo
TZA	United Republic of Tanzania
UGA	Uganda
ZMB	Zambia
ZWE	Zimbabwe

AMR_LMIC Low and middle-income America

ARG	Argentina
BRA	Brazil
CHL	Chile
COL	Colombia
CRI	Costa Rica
CUB	Cuba
DOM	Dominican Republic
JAM	Jamaica
MEX	Mexico
PAN	Panama
PER	Peru
URY	Uruguay
VEN	Venezuela (Bolivarian Republic of)

BLZ Belize
BOL Bolivia (Plurinational State of)
ECU Ecuador
GSA Guyanas South America
GTM Guatemala
HND Honduras
NIC Nicaragua
PRY Paraguay
SLV El Salvador
HTI Haiti

EMR_LMIC Low and middle-income Eastern Mediterranean

LBN Lebanon
LBY Libya
DJI Djibouti
EGY Egypt
IRN Iran (Islamic Republic of)
IRQ Iraq
JOR Jordan
PAK Pakistan
SDN Sudan
SYR Syrian Arab Republic
TUN Tunisia
AFG Afghanistan
SOM Somalia
YEM Yemen

EUR_LMIC Low and middle-income Europe

BGR Bulgaria
BLR Belarus
BLT Baltic States
KAZ Kazakhstan
OBN Other Balkans
ROU Romania
RUS Russian Federation
ALB Albania
ARM Armenia
AZE Azerbaijan

GEO Georgia
MDA Republic of Moldova
TKM Turkmenistan
UKR Ukraine
KGZ Kyrgyzstan
TJK Tajikistan
UZB Uzbekistan

SEA_LMIC Low and middle-income South-East Asia

BTN Bhutan
IDN Indonesia
IND India
LKA Sri Lanka
THA Thailand
TLS Timor-Leste
BGD Bangladesh
MMR Myanmar
NPL Nepal

WPR_LMIC Low and middle-income Western Pacific

FJI Fiji
MYS Malaysia
OPO Other Pacific Ocean
CHM China
MNG Mongolia
PHL Philippines
PNG Papua New Guinea
VUT Vanuatu
KHM Cambodia
LAO Lao People's Democratic Republic
SLB Solomon Islands
VNM Viet Nam

Appendix A8: Supplementary agricultural results

The units of reporting used for health analyses differ from those used in agricultural and economic research. Health and nutrition analysis is built around per-capita consumption values, whilst agriculture and economic analyses frequently (but not always) focus on production and consumption systems in terms of total quantities. In Tables A8.1-A8.2, we report our agricultural results in terms of total quantities (million tonnes per year) to enable comparisons between those different research fields. The economic model adopted in this study (IMPACT) formed part of a recent model comparison of global agriculture-economic models,^{95,96} where its demand projections fell within the middle two quartiles of the range of model results.⁹⁶

Tables A8.3-A8.5 list the agricultural results by country (in the units adopted in the main text), and Table A8.6 lists the climate-related changes in caloric availability in 2050 by food group and aggregate region.

Table A8.1: Global and regional consumption of fruits and vegetables (in million tonnes per year) in 2010 and 2050 for the reference scenario without climate change and for the mean of the main climate change scenarios (including standard deviation), with and without accounting for waste at the consumption level.

Region and consumption item	Baseline of 2010	Model scenarios of 2050		
		Reference scenario (without climate change)	Climate change scenarios (mean ± standard deviation)	
<i>Fruit and vegetable consumption [million tonnes/year]</i>				
Global				
net of waste at consumption	856.23	1,263.87	1,213.95	± 8.92
total	1,289.81	1,877.99	1,803.88	± 13.26
HIC				
net of waste at consumption	149.70	187.59	180.32	± 1.29
total	247.77	311.61	299.42	± 2.15
AFR_LMIC				
net of waste at consumption	60.13	152.88	147.12	± 1.15
total	82.70	209.75	201.86	± 1.58
AMR_LMIC				
net of waste at consumption	68.88	97.73	94.08	± 0.50
total	99.40	141.02	135.76	± 0.72
EMR_LMIC				
net of waste at consumption	64.43	113.14	108.80	± 0.71
total	95.09	166.98	160.57	± 1.05
EUR_LMIC				
net of waste at consumption	38.32	43.60	42.00	± 0.37
total	61.43	69.90	67.34	± 0.59
SEA_LMIC				
net of waste at consumption	140.14	283.89	271.09	± 2.29
total	195.69	396.44	378.57	± 3.20
WPR_LMIC				
net of waste at consumption	313.06	354.98	341.44	± 2.52
total	474.76	536.23	515.78	± 3.81

Table A8.2: Global and regional consumption of red meat (in million tonnes per year) in 2010 and 2050 for the reference scenario without climate change and for the mean of the main climate change scenarios (including standard deviation), with and without accounting for waste at the consumption level.

Region and consumption item	Baseline of 2010	Model scenarios of 2050		
		Reference scenario (without climate change)	Climate change scenarios (mean ± standard deviation)	
<i>Red meat consumption [million tonnes/year]</i>				
Global				
net of waste at consumption	156.63	222.40	220.80	± 0.22
total	171.03	240.92	239.18	± 0.24
HIC				
net of waste at consumption	54.10	63.16	62.64	± 0.08
total	60.59	70.71	70.13	± 0.08
AFR_LMIC				
net of waste at consumption	5.56	22.93	22.69	± 0.04
total	5.69	23.43	23.18	± 0.04
AMR_LMIC				
net of waste at consumption	19.09	26.77	26.54	± 0.03
total	20.31	28.48	28.23	± 0.04
EMR_LMIC				
net of waste at consumption	3.75	12.33	12.25	± 0.02
total	4.08	13.40	13.32	± 0.02
EUR_LMIC				
net of waste at consumption	8.64	9.39	9.32	± 0.01
total	9.71	10.55	10.47	± 0.01
SEA_LMIC				
net of waste at consumption	5.91	12.44	12.35	± 0.01
total	6.15	12.96	12.87	± 0.01
WPR_LMIC				
net of waste at consumption	59.06	74.25	73.89	± 0.07
total	63.94	80.16	79.77	± 0.08

Table A8.3: Regional and country-level consumption of fruits and vegetables (in g/cap/day) in 2010 and 2050 for the reference scenario without climate change and for the mean of the main climate change scenarios (including standard deviation), net of food waste at the consumption level.

Region	Baseline of 2010	Model scenarios of 2050		
		Reference scenario (without climate change)	Climate change scenarios (mean ± standard deviation)	
Global	342.17	378.00	363.07	± 2.67
HIC	375.87	397.73	382.31	± 2.73
AFR_LMIC	196.54	242.34	233.22	± 1.82
AMR_LMIC	324.07	362.27	348.74	± 1.84

EMR_LMIC	332.43	340.78	327.71	±	2.15
EUR_LMIC	313.98	366.02	352.63	±	3.08
SEA_LMIC	215.34	321.81	307.30	±	2.60
WPR_LMIC	539.04	602.15	579.18	±	4.28
AFG	121.18	156.12	149.59	±	1.71
AGO	118.54	114.75	109.52	±	0.73
ALB	523.69	572.60	551.75	±	4.42
ARG	298.87	321.75	309.96	±	1.75
ARM	575.39	647.33	623.81	±	5.34
AUS	309.60	320.07	307.15	±	2.58
AUT	408.62	435.65	422.56	±	2.96
AZE	439.91	420.56	404.93	±	3.23
BDI	394.31	547.50	526.33	±	3.55
BEN	164.61	195.16	186.22	±	1.48
BFA	68.07	84.00	80.43	±	0.72
BGD	76.44	105.36	100.20	±	0.97
BGR	208.60	234.92	226.42	±	1.80
BLR	344.01	396.14	381.39	±	3.50
BLT	280.80	328.50	316.91	±	2.68
BLX	347.72	372.72	360.18	±	2.73
BLZ	526.26	587.83	568.20	±	1.70
BOL	224.97	289.00	280.40	±	1.99
BRA	340.82	371.56	356.09	±	1.69
BTN	325.71	472.15	450.71	±	2.60
BWA	133.06	180.04	174.92	±	1.35
CAF	134.76	168.36	160.84	±	1.15
CAN	369.91	382.25	365.18	±	2.95
CHL	298.96	357.50	346.98	±	2.54
CHM	580.91	663.34	638.17	±	4.78
CHP	276.94	291.84	282.05	±	1.97
CIV	236.15	290.34	278.69	±	3.60
CMR	342.57	406.54	390.14	±	3.81
COD	105.77	146.06	139.95	±	1.32
COG	203.25	251.08	240.25	±	2.05
COL	294.29	336.66	327.31	±	1.80
CRB	102.72	116.38	114.06	±	0.43
CRI	342.05	384.71	372.54	±	1.36
CUB	487.41	597.51	579.95	±	3.30
CYP	384.31	390.76	377.69	±	2.08
CZE	271.28	300.35	290.28	±	2.07
DEU	304.48	325.67	314.84	±	2.35
DJI	130.08	146.71	140.97	±	1.14
DNK	379.58	401.68	388.29	±	2.62
DOM	423.72	474.61	459.95	±	2.23
DZA	352.85	387.21	374.53	±	2.20

ECU	346.25	424.57	412.13	±	2.49
EGY	582.21	641.97	617.83	±	3.96
ERI	16.42	19.68	18.80	±	0.19
ETH	55.92	66.25	63.56	±	0.46
FJI	158.50	184.72	180.48	±	0.82
FNP	285.44	303.47	293.00	±	1.90
FRP	366.67	383.89	370.10	±	2.38
GAB	375.31	410.64	394.58	±	5.62
GEO	223.90	265.35	255.92	±	1.94
GHA	364.92	441.87	424.08	±	5.66
GIN	343.12	442.24	422.77	±	3.43
GMB	83.25	97.48	93.15	±	0.93
GNB	143.28	176.74	169.13	±	1.78
GNQ	204.49	203.77	194.98	±	2.55
GRC	729.74	786.39	758.99	±	5.56
GSA	170.60	214.88	208.00	±	1.02
GTM	233.11	279.81	270.26	±	1.25
HND	268.08	319.22	310.19	±	1.75
HRV	266.03	289.88	280.61	±	2.10
HTI	183.36	255.77	247.97	±	1.18
HUN	372.60	409.55	395.96	±	3.09
IDN	203.00	252.19	239.24	±	1.69
IND	226.50	355.83	339.86	±	2.96
IRL	310.65	327.83	315.46	±	1.71
IRN	719.96	755.76	729.54	±	4.70
IRQ	311.50	348.67	334.95	±	1.86
ISL	304.37	334.10	322.58	±	1.98
ISR	623.03	650.29	618.51	±	5.29
ITP	560.60	591.69	570.61	±	3.88
JAM	387.57	429.31	420.65	±	1.01
JOR	340.86	391.74	378.76	±	2.43
JPN	292.95	306.92	297.77	±	1.78
KAZ	321.35	361.41	346.92	±	2.94
KEN	206.10	248.94	239.44	±	1.61
KGZ	305.31	355.30	340.85	±	3.18
KHM	126.07	164.97	159.27	±	0.95
KOR	544.16	608.49	589.14	±	3.64
LAO	373.07	465.79	448.95	±	2.65
LBN	622.85	665.64	642.61	±	3.90
LBR	186.93	222.84	212.98	±	1.75
LBY	473.89	512.17	494.97	±	2.94
LKA	141.34	172.77	165.80	±	1.69
LSO	77.96	124.67	120.91	±	1.00
MDA	279.09	344.71	332.83	±	2.87
MDG	125.79	151.54	144.35	±	0.73

MEX	378.42	421.91	403.52	±	2.36
MLI	142.82	163.12	155.73	±	1.11
MMR	248.41	343.90	333.14	±	3.71
MNG	100.05	145.53	141.77	±	0.93
MOR	458.51	518.41	501.62	±	3.00
MOZ	49.73	74.52	71.53	±	0.46
MRT	51.28	59.20	56.58	±	0.38
MWI	188.02	253.63	244.88	±	2.21
MYS	186.36	210.83	203.62	±	1.14
NAM	108.18	150.84	145.76	±	1.09
NER	123.40	143.90	137.37	±	1.20
NGA	277.46	334.97	323.15	±	1.76
NIC	75.89	104.55	101.31	±	0.59
NLD	382.28	405.41	390.86	±	2.56
NOR	345.05	354.18	342.23	±	2.15
NPL	220.92	287.38	275.82	±	2.67
NZL	364.82	380.55	363.32	±	3.29
OAD	186.67	281.11	275.62	±	1.22
OBN	277.05	315.44	305.11	±	2.50
OIO	155.06	194.25	190.62	±	0.77
OPO	145.13	165.31	162.06	±	0.62
OSA	27.60	29.09	28.11	±	0.22
PAK	131.65	153.96	146.83	±	1.00
PAN	235.90	282.61	273.97	±	1.75
PER	290.17	343.97	333.65	±	2.20
PHL	340.18	392.77	377.32	±	1.58
PNG	798.68	1,039.31	1,015.20	±	6.70
POL	296.81	326.04	314.11	±	2.64
PRT	503.98	531.05	512.59	±	3.65
PRY	293.76	344.87	332.80	±	1.28
RAP	280.73	306.19	296.02	±	1.72
ROU	459.26	505.12	486.96	±	4.03
RUS	292.48	342.09	329.60	±	2.98
RWA	406.84	516.22	498.35	±	6.65
SAU	372.19	400.32	384.47	±	2.06
SDN	244.19	288.70	276.86	±	1.86
SEN	143.12	162.37	155.24	±	1.17
SLB	136.87	173.88	169.16	±	1.49
SLE	169.48	201.66	192.40	±	1.56
SLV	270.05	305.61	296.48	±	1.63
SOM	62.68	99.32	96.53	±	0.65
SPP	435.02	445.98	429.73	±	2.79
SVK	243.40	264.27	255.26	±	1.90
SVN	407.02	450.55	436.54	±	3.65
SWE	335.87	358.34	345.95	±	2.25

SWZ	196.77	219.46	208.54	±	0.89
SYR	385.40	454.64	439.03	±	2.57
TCD	42.51	57.79	55.65	±	0.42
TGO	79.28	94.12	89.92	±	0.80
THA	357.15	429.91	411.72	±	1.75
TJK	234.25	260.87	250.67	±	2.09
TKM	344.39	404.82	388.90	±	3.47
TLS	80.94	93.37	91.43	±	0.29
TUN	557.88	628.60	607.72	±	3.64
TUR	611.20	658.55	637.51	±	4.25
TZA	215.41	264.99	255.00	±	1.72
UGA	404.73	488.74	473.38	±	6.51
UKP	375.96	403.29	389.54	±	2.54
UKR	288.48	351.76	339.37	±	2.74
URY	263.59	303.74	293.24	±	1.98
USA	382.75	399.64	381.27	±	3.03
UZB	337.58	428.79	413.07	±	3.87
VEN	246.35	270.13	261.48	±	1.31
VNM	304.91	385.05	366.88	±	4.00
VUT	275.55	323.52	317.07	±	1.46
YEM	139.31	162.96	156.78	±	0.93
ZAF	156.85	182.87	174.46	±	1.38
ZMB	72.12	93.36	89.52	±	0.62
ZWE	53.97	69.19	66.14	±	0.44

Table A8.4: Regional and country-level consumption of red meat (in g/cap/day) in 2010 and 2050 for the reference scenario without climate change and for the mean of the main climate change scenarios (including standard deviation), net of food waste at the consumption level.

Region	Baseline of 2010	Model scenarios of 2050			
		Reference scenario (without climate change)	Climate change scenarios (mean ± standard deviation)		
Global	62.59	66.52	66.04	±	0.07
HIC	135.84	133.91	132.81	±	0.16
AFR_LMIC	18.16	36.36	35.96	±	0.06
AMR_LMIC	89.80	99.25	98.38	±	0.12
EMR_LMIC	19.36	37.13	36.90	±	0.05
EUR_LMIC	70.82	78.82	78.21	±	0.09
SEA_LMIC	9.08	14.10	14.00	±	0.01
WPR_LMIC	101.69	125.95	125.33	±	0.12
AFG	16.70	35.45	35.16	±	0.06
AGO	39.10	43.82	43.37	±	0.07
ALB	66.39	70.35	69.86	±	0.07
ARG	162.32	163.06	161.84	±	0.23

ARM	53.25	77.75	77.48	±	0.04
AUS	146.88	159.27	157.98	±	0.18
AUT	207.62	196.26	194.12	±	0.38
AZE	32.45	34.06	33.98	±	0.02
BDI	6.96	21.15	20.91	±	0.03
BEN	9.39	17.61	17.43	±	0.03
BFA	28.04	92.37	91.25	±	0.19
BGD	4.09	8.65	8.61	±	0.01
BGR	72.35	80.85	80.21	±	0.10
BLR	123.63	131.97	130.86	±	0.17
BLT	103.07	110.60	109.59	±	0.18
BLX	128.77	124.98	123.72	±	0.19
BLZ	45.94	53.08	52.60	±	0.07
BOL	84.39	119.20	118.33	±	0.12
BRA	127.66	138.52	137.11	±	0.21
BTN	30.43	53.69	53.35	±	0.07
BWA	32.60	62.10	61.46	±	0.13
CAF	58.98	143.33	141.67	±	0.27
CAN	141.26	131.44	130.53	±	0.13
CHL	102.18	118.36	117.41	±	0.13
CHM	108.42	133.96	133.28	±	0.13
CHP	128.03	123.46	122.21	±	0.19
CIV	7.86	18.50	18.30	±	0.03
CMR	16.88	29.41	29.12	±	0.05
COD	1.81	8.86	8.76	±	0.01
COG	10.55	23.30	23.05	±	0.03
COL	54.18	62.14	61.72	±	0.07
CRB	14.47	23.67	23.55	±	0.02
CRI	59.20	71.13	70.60	±	0.07
CUB	35.00	45.90	45.46	±	0.07
CYP	110.23	108.45	108.24	±	0.04
CZE	133.25	141.30	140.02	±	0.25
DEU	158.03	148.69	147.05	±	0.29
DJI	25.49	92.37	91.16	±	0.22
DNK	192.81	183.99	182.09	±	0.30
DOM	47.20	55.48	54.99	±	0.07
DZA	16.92	26.59	26.59	±	0.01
ECU	73.19	94.43	93.70	±	0.10
EGY	30.06	54.74	54.32	±	0.09
ERI	8.04	17.51	17.31	±	0.04
ETH	13.60	14.97	14.80	±	0.03
FJI	37.27	71.19	70.89	±	0.04
FNP	125.80	121.61	120.36	±	0.19
FRP	141.51	137.40	136.04	±	0.19
GAB	40.30	56.67	56.13	±	0.07

GEO	56.16	87.54	87.12	±	0.06
GHA	6.57	21.72	21.47	±	0.04
GIN	12.91	37.04	36.64	±	0.07
GMB	9.96	29.88	29.56	±	0.06
GNB	32.52	65.08	64.32	±	0.12
GNQ	0.90	0.85	0.84	±	0.00
GRC	107.53	110.16	109.29	±	0.13
GSA	11.94	16.88	16.74	±	0.02
GTM	27.05	36.38	36.07	±	0.05
HND	34.55	46.00	45.70	±	0.04
HRV	95.74	96.51	95.66	±	0.16
HTI	21.58	34.98	34.69	±	0.04
HUN	117.99	123.27	122.12	±	0.23
IDN	12.54	17.78	17.74	±	0.01
IND	5.99	8.84	8.75	±	0.02
IRL	155.92	150.04	148.54	±	0.22
IRN	16.85	24.22	24.21	±	0.01
IRQ	4.13	4.47	4.45	±	0.00
ISL	72.28	71.33	70.61	±	0.11
ISR	68.93	67.28	66.82	±	0.09
ITP	156.43	149.55	148.02	±	0.23
JAM	27.19	42.85	42.66	±	0.03
JOR	22.09	39.21	39.22	±	0.01
JPN	70.21	80.00	79.27	±	0.13
KAZ	89.07	109.23	108.40	±	0.12
KEN	30.70	48.35	47.79	±	0.11
KGZ	56.93	91.10	90.72	±	0.06
KHM	40.47	60.80	60.60	±	0.03
KOR	107.28	184.48	183.94	±	0.11
LAO	41.65	67.22	67.02	±	0.03
LBN	64.40	96.88	96.83	±	0.03
LBR	9.63	34.55	34.15	±	0.08
LBY	13.39	20.47	20.48	±	0.01
LKA	5.21	14.32	14.22	±	0.02
LSO	24.48	49.12	48.58	±	0.08
MDA	37.42	46.89	46.49	±	0.07
MDG	24.54	48.26	47.72	±	0.08
MEX	77.06	88.77	88.07	±	0.10
MLI	21.67	43.79	43.30	±	0.10
MMR	29.67	66.66	66.47	±	0.03
MNG	56.72	215.46	215.34	±	0.08
MOR	15.46	32.19	32.16	±	0.01
MOZ	18.56	68.85	68.11	±	0.14
MRT	23.46	50.20	49.54	±	0.13
MWI	10.06	22.91	22.65	±	0.04

MYS	39.69	59.70	59.60	±	0.02
NAM	35.99	68.26	67.56	±	0.11
NER	35.85	112.54	111.17	±	0.28
NGA	10.00	25.07	24.76	±	0.04
NIC	15.91	24.52	24.36	±	0.02
NLD	123.67	118.60	117.37	±	0.19
NOR	106.68	101.33	100.33	±	0.14
NPL	20.82	52.36	52.01	±	0.08
NZL	105.20	113.95	113.16	±	0.11
OAD	15.89	64.93	64.58	±	0.07
OBN	30.89	33.35	33.08	±	0.04
OIO	8.89	17.54	17.48	±	0.01
OPO	44.46	72.79	72.47	±	0.05
OSA	3.38	3.81	3.80	±	0.00
PAK	17.96	29.89	29.57	±	0.07
PAN	75.33	97.91	97.23	±	0.09
PER	19.86	26.09	25.89	±	0.03
PHL	60.38	92.03	91.67	±	0.07
PNG	33.72	70.53	70.15	±	0.08
POL	134.94	139.80	138.50	±	0.26
PRT	137.06	131.49	130.11	±	0.22
PRY	106.88	126.56	125.35	±	0.19
RAP	9.05	12.30	12.29	±	0.00
ROU	91.57	98.57	97.72	±	0.15
RUS	80.58	86.47	85.75	±	0.10
RWA	10.04	26.02	25.72	±	0.04
SAU	11.83	15.97	15.95	±	0.01
SDN	27.03	77.24	77.06	±	0.05
SEN	16.76	32.10	31.75	±	0.06
SLB	24.97	58.09	57.78	±	0.06
SLE	5.07	12.42	12.28	±	0.02
SLV	27.87	34.54	34.31	±	0.03
SOM	17.61	87.11	85.95	±	0.23
SPP	170.99	158.06	156.35	±	0.30
SVK	104.56	109.49	108.50	±	0.19
SVN	158.53	161.73	160.42	±	0.21
SWE	142.55	138.99	137.59	±	0.21
SWZ	71.90	107.28	106.05	±	0.21
SYR	8.33	17.56	17.54	±	0.01
TCD	22.19	45.84	45.32	±	0.10
TGO	8.61	26.87	26.56	±	0.04
THA	43.69	75.34	75.04	±	0.06
TJK	13.74	25.04	24.97	±	0.01
TKM	58.87	87.20	86.92	±	0.06
TLS	31.32	61.72	61.42	±	0.06

TUN	17.66	35.97	35.92	±	0.02
TUR	12.78	19.83	19.75	±	0.02
TZA	20.80	38.86	38.40	±	0.09
UGA	21.74	42.31	41.83	±	0.07
UKP	113.65	111.03	109.94	±	0.16
UKR	57.37	64.68	64.15	±	0.08
URY	98.69	112.89	112.04	±	0.12
USA	179.66	169.53	168.34	±	0.17
UZB	53.36	63.77	63.34	±	0.08
VEN	59.16	69.87	69.41	±	0.07
VNM	84.97	124.70	124.00	±	0.14
VUT	67.21	139.80	139.07	±	0.13
YEM	9.95	15.65	15.64	±	0.01
ZAF	52.66	85.49	85.01	±	0.07
ZMB	17.77	36.45	36.07	±	0.06
ZWE	27.70	106.73	105.63	±	0.18

Table A8.5: Regional and country-level food availability (in kcal/cap/day) in 2010 and 2050 for the reference scenario without climate change and for the mean of the main climate change scenarios (including standard deviation).

Region	Baseline of 2010	Model scenarios of 2050			
		Reference scenario (without climate change)	Climate change scenarios (mean ± standard deviation)		
Global	2,568.91	2,878.29	2,787.23	±	9.36
HIC	2,892.16	2,899.93	2,850.39	±	7.78
AFR_LMIC	2,374.85	2,833.26	2,712.98	±	12.73
AMR_LMIC	2,713.57	2,872.06	2,805.39	±	10.17
EMR_LMIC	2,439.68	2,695.64	2,626.70	±	12.70
EUR_LMIC	2,591.03	2,778.24	2,732.29	±	11.37
SEA_LMIC	2,345.65	2,785.64	2,672.81	±	12.87
WPR_LMIC	2,650.87	3,141.85	3,046.52	±	12.82
AFG	2,166.25	2,426.39	2,334.85	±	31.87
AGO	2,336.34	2,382.51	2,271.10	±	12.98
ALB	2,442.59	2,643.21	2,597.18	±	14.78
ARG	2,971.43	3,124.75	3,075.68	±	8.59
ARM	2,270.27	2,624.85	2,569.69	±	15.11
AUS	2,618.69	2,636.20	2,591.98	±	6.48
AUT	3,232.42	3,246.99	3,194.86	±	10.39
AZE	2,505.94	2,496.93	2,441.17	±	19.69
BDI	2,036.38	2,855.44	2,720.56	±	15.84
BEN	2,467.06	2,838.55	2,670.17	±	16.98
BFA	2,586.76	2,969.45	2,879.65	±	11.49

BGD	2,405.57	2,708.65	2,572.45	±	9.82
BGR	2,416.75	2,641.89	2,602.91	±	8.51
BLR	2,483.91	2,503.42	2,467.96	±	5.86
BLT	3,330.88	3,354.26	3,338.53	±	3.14
BLX	3,348.70	3,320.64	3,294.87	±	4.89
BLZ	2,512.42	2,661.30	2,595.86	±	5.71
BOL	2,012.84	2,420.49	2,356.45	±	7.79
BRA	2,951.12	3,124.47	3,057.80	±	5.42
BTN	2,145.54	2,553.34	2,445.92	±	26.62
BWA	2,153.47	2,576.14	2,481.25	±	12.84
CAF	1,931.00	2,853.15	2,720.00	±	16.80
CAN	2,807.53	2,774.58	2,724.48	±	7.29
CHL	2,719.06	2,889.27	2,831.42	±	6.53
CHM	2,683.92	3,246.90	3,152.40	±	14.35
CHP	2,993.80	3,009.32	2,964.32	±	8.52
CIV	2,614.23	3,039.83	2,883.80	±	14.96
CMR	2,282.70	2,716.05	2,585.71	±	14.85
COD	1,721.88	2,279.59	2,183.67	±	13.75
COG	2,187.50	2,801.53	2,661.52	±	24.63
COL	2,525.22	2,704.78	2,642.80	±	9.64
CRB	3,040.44	3,085.53	3,077.75	±	1.32
CRI	2,711.87	2,927.25	2,856.64	±	5.56
CUB	2,315.58	2,562.73	2,484.96	±	7.33
CYP	2,254.85	2,198.73	2,163.66	±	4.69
CZE	2,910.71	3,071.67	3,030.26	±	9.55
DEU	3,077.61	3,081.58	3,034.38	±	8.38
DJI	2,007.09	2,406.09	2,310.15	±	21.32
DNK	2,895.43	2,911.06	2,866.72	±	9.84
DOM	2,336.51	2,554.99	2,490.23	±	4.57
DZA	2,816.93	2,922.70	2,861.79	±	16.46
ECU	2,094.17	2,290.18	2,233.55	±	5.15
EGY	2,938.87	3,239.16	3,136.58	±	9.92
ERI	1,798.42	2,246.41	2,176.44	±	25.32
ETH	2,090.91	2,568.45	2,496.55	±	16.42
FJI	2,861.28	3,657.93	3,542.05	±	22.28
FNP	2,753.72	2,744.07	2,702.80	±	11.54
FRP	3,073.72	3,039.39	2,991.07	±	8.42
GAB	2,639.15	2,942.37	2,803.59	±	17.97
GEO	2,416.85	2,942.95	2,891.10	±	11.47
GHA	2,715.96	3,074.28	2,914.92	±	19.58
GIN	2,478.67	3,273.80	3,085.25	±	16.81
GMB	2,403.94	2,921.54	2,803.85	±	17.19
GNB	2,354.85	2,720.19	2,558.06	±	11.13
GNQ	2,554.19	2,357.11	2,234.08	±	21.87
GRC	3,142.68	3,213.80	3,162.23	±	12.49

GSA	2,517.33	2,668.42	2,624.58	±	3.21
GTM	2,040.73	2,321.75	2,259.70	±	24.68
HND	2,407.21	2,769.91	2,704.19	±	21.56
HRV	2,656.24	2,729.88	2,693.13	±	7.84
HTI	1,708.11	2,128.28	2,065.35	±	5.50
HUN	2,992.72	3,141.69	3,101.61	±	9.34
IDN	2,495.40	3,034.37	2,884.31	±	9.83
IND	2,288.29	2,747.69	2,642.33	±	16.27
IRL	2,969.12	2,991.52	2,944.43	±	9.87
IRN	2,864.70	2,954.71	2,879.10	±	16.24
IRQ	2,645.62	2,899.76	2,812.72	±	23.72
ISL	2,867.31	2,947.22	2,905.09	±	8.64
ISR	3,095.28	3,292.61	3,214.40	±	13.71
ITP	3,292.32	3,311.34	3,279.65	±	8.15
JAM	2,560.79	2,894.69	2,827.27	±	8.79
JOR	2,897.25	3,415.35	3,343.11	±	10.05
JPN	2,453.90	2,443.27	2,392.30	±	5.78
KAZ	2,442.54	2,705.56	2,652.11	±	15.05
KEN	2,049.15	2,847.27	2,716.10	±	37.12
KGZ	2,299.55	2,679.74	2,625.15	±	12.15
KHM	2,232.78	2,439.18	2,320.65	±	5.08
KOR	2,740.54	2,927.71	2,868.08	±	6.47
LAO	2,206.34	2,355.38	2,240.91	±	4.77
LBN	2,753.29	3,029.78	2,967.82	±	9.24
LBR	2,381.97	2,847.84	2,673.10	±	19.75
LBY	2,605.59	2,817.15	2,759.82	±	13.46
LKA	2,338.20	2,564.05	2,457.36	±	11.94
LSO	2,417.60	2,727.53	2,595.83	±	47.79
MDA	2,350.09	2,761.50	2,718.97	±	11.60
MDG	2,035.57	2,482.89	2,284.80	±	9.39
MEX	2,954.33	3,025.35	2,947.81	±	27.60
MLI	2,355.90	2,649.54	2,534.29	±	8.11
MMR	2,350.99	2,611.04	2,495.89	±	7.39
MNG	2,287.71	3,393.64	3,321.80	±	25.60
MOR	3,236.67	3,707.64	3,637.09	±	14.84
MOZ	2,151.97	2,640.05	2,491.99	±	18.33
MRT	2,718.06	3,283.54	3,161.00	±	29.95
MWI	2,251.50	2,431.78	2,306.09	±	53.14
MYS	2,785.21	3,302.40	3,228.30	±	15.12
NAM	2,278.96	2,886.46	2,781.53	±	14.42
NER	2,257.59	2,932.87	2,842.29	±	20.10
NGA	2,806.69	3,194.26	3,058.42	±	16.19
NIC	2,133.22	2,551.82	2,474.28	±	19.16
NLD	2,838.35	2,841.29	2,799.05	±	7.02
NOR	2,955.96	2,890.57	2,843.09	±	12.14

NPL	2,296.37	2,821.58	2,699.92 ±	9.81
NZL	2,462.03	2,570.10	2,525.70 ±	8.20
OAD	2,459.88	2,768.60	2,740.78 ±	2.49
OBN	3,343.40	3,427.79	3,410.40 ±	2.64
OIO	2,600.08	2,735.48	2,711.51 ±	3.65
OPO	2,693.24	2,825.79	2,806.09 ±	3.52
OSA	3,050.02	3,035.97	3,014.42 ±	2.45
PAK	2,180.15	2,491.57	2,438.03 ±	9.83
PAN	2,347.75	2,598.17	2,523.49 ±	5.27
PER	2,308.53	2,513.11	2,433.81 ±	5.84
PHL	2,418.65	2,596.38	2,503.85 ±	6.47
PNG	2,207.64	3,055.80	2,980.48 ±	8.70
POL	2,953.75	3,104.70	3,064.36 ±	10.21
PRT	3,052.36	3,140.76	3,079.19 ±	10.90
PRY	2,537.20	2,750.28	2,686.68 ±	16.97
RAP	3,269.00	3,411.57	3,313.93 ±	21.73
ROU	2,402.04	2,553.22	2,514.52 ±	8.16
RUS	2,766.29	2,930.39	2,882.56 ±	10.28
RWA	2,085.11	3,037.86	2,907.00 ±	16.35
SAU	2,781.54	2,906.64	2,838.64 ±	7.87
SDN	2,138.46	2,440.27	2,385.31 ±	7.92
SEN	2,322.04	2,721.97	2,565.34 ±	10.24
SLB	2,428.77	2,954.64	2,860.72 ±	10.61
SLE	2,098.53	2,389.50	2,243.47 ±	11.55
SLV	2,401.25	2,546.05	2,482.20 ±	23.87
SOM	1,545.65	2,819.31	2,757.40 ±	9.50
SPP	2,864.48	2,819.30	2,771.12 ±	8.91
SVK	2,491.31	2,594.83	2,557.94 ±	8.84
SVN	2,720.31	2,818.76	2,777.98 ±	7.12
SWE	2,715.72	2,721.98	2,679.88 ±	9.41
SWZ	2,376.59	2,791.05	2,665.94 ±	24.03
SYR	2,633.98	3,142.79	3,077.29 ±	10.99
TCD	2,023.21	2,517.72	2,435.75 ±	11.87
TGO	2,315.43	2,792.82	2,632.84 ±	25.25
THA	2,739.83	3,085.86	3,009.50 ±	3.56
TJK	1,832.33	2,174.50	2,125.66 ±	15.38
TKM	2,420.84	2,775.02	2,713.96 ±	21.54
TLS	2,076.92	2,596.92	2,500.46 ±	9.95
TUN	2,969.90	3,357.28	3,288.87 ±	17.92
TUR	3,025.61	3,094.74	3,031.88 ±	13.32
TZA	2,207.67	2,711.31	2,579.43 ±	23.97
UGA	2,366.76	2,905.16	2,796.68 ±	14.47
UKP	2,934.04	2,966.19	2,917.00 ±	11.04
UKR	2,390.67	2,607.53	2,566.67 ±	7.37
URY	2,714.51	2,910.41	2,848.27 ±	6.94

USA	2,907.66	2,820.88	2,772.26	±	5.97
UZB	2,115.05	2,468.52	2,411.82	±	21.69
VEN	2,405.29	2,511.38	2,454.34	±	11.37
VNM	2,489.61	2,756.79	2,640.25	±	6.64
VUT	2,733.66	3,419.38	3,306.06	±	11.53
YEM	1,875.84	2,060.40	2,016.77	±	7.17
ZAF	2,980.50	3,488.20	3,387.83	±	18.61
ZMB	1,909.38	2,880.79	2,724.42	±	52.08
ZWE	2,040.07	2,731.40	2,623.07	±	39.42

Table A8.6: Food availability (in kcal per capita per day) in 2050 by major food group and aggregate region (World, HIC: high-income countries, UMC: upper middle-income countries, LMC: lower middle-income countries, LIC: low-income countries) for the reference scenario without climate change (SSP2_NoCC) and for the mean of the main climate change scenarios (including standard deviation) (SSP2_NoCC, SSP2_CC_std), with and without accounting for waste at the consumption level.

Scenario and region	Food availability (kcal/cap/d)								
	Total	Fruits & vegetables	All meat	Diary	Cereals	Roots & tubers	Oilseeds & pulses	Processed oils	Sugar crops
<i>without accounting for waste at the consumption level</i>									
World									
SSP2_NoCC	3,106.9	214.3	229.6	197.2	1,356.6	160.3	137.9	210.3	244.3
SSP2_CC	3,008.3	205.9	227.8	196.5	1,287.7	152.6	133.8	208.1	241.4
SSP2_CC_std	10.8	1.6	0.3	0.1	10.3	1.1	0.7	0.3	2.5
HIC									
SSP2_NoCC	3,433.6	222.3	348.5	344.3	937.6	98.2	65.0	214.0	300.7
SSP2_CC	3,372.5	213.8	345.7	343.7	902.2	95.9	62.9	211.9	297.6
SSP2_CC_std	10.8	1.5	0.5	0.1	11.9	0.4	0.4	0.3	2.7
UMC									
SSP2_NoCC	3,214.8	192.3	311.3	257.3	1,186.4	125.8	113.7	185.0	395.7
SSP2_CC	3,143.7	185.4	308.4	256.7	1,140.8	121.9	111.1	183.3	391.5
SSP2_CC_std	6.5	1.2	0.4	0.1	4.7	0.5	0.6	0.3	3.6
LMC									
SSP2_NoCC	3,118.1	224.0	218.1	182.2	1,478.9	146.1	139.9	228.8	240.1
SSP2_CC	3,010.0	214.9	216.6	181.3	1,399.8	139.3	136.0	226.4	236.9
SSP2_CC_std	13.8	1.5	0.3	0.1	14.1	1.0	0.6	0.4	2.6
LIC									
SSP2_NoCC	2,730.0	187.7	136.0	95.3	1,394.8	270.9	196.1	161.5	113.3
SSP2_CC	2,612.7	180.6	134.8	94.8	1,314.7	253.9	189.1	159.4	111.9
SSP2_CC_std	10.2	2.0	0.2	0.1	6.3	2.6	1.2	0.2	1.2

with accounting for waste at the consumption level

World

SSP2_NoCC	2,878.3	189.4	212.9	187.6	1,225.3	150.8	135.3	210.3	244.3
SSP2_CC	2,787.2	182.0	211.2	186.9	1,162.3	143.4	131.3	208.1	241.4
SSP2_CC_std	9.4	1.4	0.3	0.1	9.0	1.0	0.7	0.3	2.5

HIC

SSP2_NoCC	2,899.9	174.8	311.7	308.9	719.1	77.4	62.5	214.0	300.7
SSP2_CC	2,850.4	168.1	309.1	308.3	692.0	75.6	60.6	211.9	297.6
SSP2_CC_std	7.8	1.2	0.4	0.1	9.0	0.3	0.4	0.3	2.7

UMC

SSP2_NoCC	2,983.5	170.1	291.2	246.0	1,046.5	115.5	111.4	185.0	395.7
SSP2_CC	2,918.8	164.0	288.5	245.4	1,005.8	111.8	108.8	183.3	391.5
SSP2_CC_std	6.2	1.0	0.4	0.1	4.0	0.5	0.6	0.3	3.6

LMC

SSP2_NoCC	2,920.4	200.3	202.8	176.8	1,346.8	138.6	137.2	228.8	240.1
SSP2_CC	2,820.5	192.2	201.3	176.0	1,274.4	132.2	133.4	226.4	236.9
SSP2_CC_std	12.3	1.4	0.2	0.1	12.6	0.9	0.6	0.4	2.6

LIC

SSP2_NoCC	2,652.0	176.1	131.2	94.1	1,346.5	264.8	194.0	161.5	113.3
SSP2_CC	2,538.0	169.4	130.1	93.6	1,268.7	248.1	187.1	159.4	111.9
SSP2_CC_std	9.9	1.9	0.2	0.1	6.2	2.5	1.2	0.2	1.2

Appendix A9: Supplementary health results

Table A9.1 lists the health impacts associated with the changes in food availability and consumption for the future consumption scenarios with and without climate change. The basis for comparison is a baseline with 2010 levels of food consumption and weight levels, but with all-cause death rates and population structures of 2050. Adopting this baseline allowed us to isolate the health impacts of changes in dietary and weight-related risk factors between 2010 and 2050 when comparing it to the reference and climate change scenarios, and to estimate the impacts of climate change in 2050 by calculating the difference between the reference scenario and the climate-change scenarios.

Figure A9.1 disaggregated the total number of climate-related deaths by risk factor and cause of death, and Tables A9.2-A9.4 resolve the climate-related health impacts on the country level. Table A9.2 lists the climate-related deaths in the ten most impacted and three least impacted countries. The greatest numbers of climate-related deaths in 2050 occurred in China (248 thousand; 95% CI: 169-332 thousand; CC SD: 51 thousand) and India (136 thousand; 95% CI: 88-176 thousand; CC SD: 25 thousand), whose numbers of climate-related deaths were an order of magnitude larger than those of any other country. China alone accounted for 43% of all climate-related deaths, and China and India together accounted for 73%. Venezuela and South Africa were the two countries with the least negative climate-related health impacts, leading to a small number of avoided deaths. Tables A9.3 and A9.4 list the climate-related deaths by region and country in per capita terms and in absolute, respectively, and Tables A9.5 and A9.6 list those by risk factor.

Table A9.1: Deaths avoided (in thousands) due to changes in dietary and weight-related risk factors for the reference scenario without climate change and for the mean of the main climate-change scenarios in 2050. The basis for comparison is a baseline with 2010 levels of food consumption and weight levels, but with all-cause death rates and population structures of 2050. Adopting this baseline allowed us to isolate the health impacts of changes in dietary and weight-related risk factors between 2010 and 2050 when comparing it to the reference and climate change scenarios, and to estimate the impacts of climate change in 2050 by calculating the difference between the reference scenario and the climate-change scenarios. Low and high values represent 95% confidence intervals, and CC SD represents the standard deviation of the main climate-change scenarios.

Region	Reference scenario (without climate change)			Climate change scenario (average and standard deviation)			
	mean	low	high	mean	low	high	CC SD
Global	1,877	942	2,820	1,348	628	2,084	105
HIC	113	73	152	74	50	99	9
AFR_LMIC	156	69	242	128	58	198	4
AMR_LMIC	-6	-33	21	-8	-27	10	6
EMR_LMIC	-43	-86	-2	-56	-87	-25	2
EUR_LMIC	13	-42	68	-1	-43	41	4
SEA_LMIC	1,119	773	1,450	956	672	1,233	29
WPR_LMIC	519	190	877	255	12	523	53

Regional abbreviations follow the WHO-World Bank classification: HIC: high-income countries; AFR_LMIC: low and middle-income countries of Africa; AMR_LMIC: low and middle-income countries of America; EMR_LMIC: low and middle-income countries of the Eastern Mediterranean; EUR_LMIC: low and middle income countries of Europe; SEA_LMIC: low and middle-income countries of South-East Asia; WPR_LMIC: low and middle-income countries of the Western Pacific). Appendix A6 lists the countries included in each region.

Figure A9.1: Total number of climate-related deaths (in thousands) by cause of death and risk factor (FVC: fruit and vegetable consumption; MTC: red-meat consumption; UND: underweight; OVW: overweight; OBS: obesity).

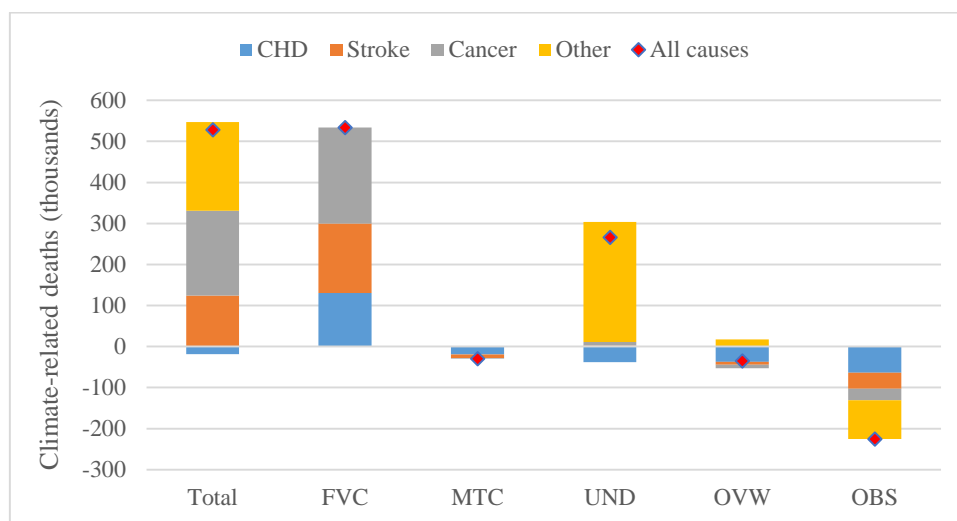


Table A9.2: Climate-related deaths (in thousands) in the ten most impacted and three least impacted countries. Low and high values represent 95% confidence intervals, and CC SD represents the standard deviation of the main climate-change scenarios.

Country	Climate-related deaths (thousand)				
	mean	low	high	CC SD	% of total
China	247.97	168.54	331.49	50.74	47%
India	135.97	87.69	175.80	24.62	26%
Vietnam	10.70	6.64	14.29	1.92	2%
Bangladesh	9.95	6.77	13.29	0.97	2%
USA	8.64	5.27	11.72	2.25	2%
Indonesia	7.95	1.50	14.53	1.57	2%
Japan	7.62	6.84	8.41	1.49	1%
Russia	7.46	1.65	13.17	2.26	1%
Iran	5.66	2.53	8.65	0.89	1%
DR Congo	4.94	3.09	6.84	0.73	1%
Iraq	-0.57	-1.27	0.09	0.37	0%
South Africa	-0.60	-0.91	-0.23	0.39	0%
Venezuela	-0.94	-1.36	-0.58	0.48	0%

Table A9.3: Climate-related deaths per capita (in deaths per million) by region and country. Low and high values represent 95% confidence intervals, and CC SD represents the standard deviation of the main climate-change scenarios.

Region	Climate-related deaths per capita (per million)			
	mean	low	high	CC SD
Global	77.99	46.35	108.54	15.52
HIC	37.17	22.65	51.13	9.14
AFR_LMIC	26.43	11.19	41.73	3.57
AMR_LMIC	4.73	-10.37	19.24	9.76
EMR_LMIC	20.23	1.62	37.98	3.85
EUR_LMIC	55.01	6.76	101.28	14.47
SEA_LMIC	89.51	55.63	118.48	15.64
WPR_LMIC	198.60	133.56	266.34	40.05
AFG	40.77	28.93	51.86	14.61
AGO	54.06	59.10	48.82	6.05
ALB	88.10	43.23	125.68	14.21
ARG	5.47	-5.25	15.73	2.44
ARM	80.95	22.99	132.89	13.79
AUS	5.74	-0.67	12.72	5.19
AUT	29.04	8.84	46.10	14.60
AZE	46.22	85.82	6.94	3.13
BDI	44.42	25.79	60.99	4.72
BEN	30.49	3.88	57.13	2.60
BFA	32.15	21.85	43.22	3.48
BGD	66.65	45.33	89.01	6.50
BGR	4.82	-19.40	25.98	5.30
BLR	69.46	-20.99	151.52	33.00
BLT	83.52	39.83	126.69	27.22
BLX	35.71	19.14	52.78	10.39
BLZ	-6.15	-17.40	5.30	4.50
BOL	-26.39	-38.97	-15.46	7.17
BRA	24.25	6.88	41.66	6.53
BTN	46.02	17.55	68.73	14.56
BWA	-2.25	-16.55	12.80	2.27
CAF	-7.57	-21.14	4.44	1.69
CAN	29.52	24.87	33.36	7.36
CHL	4.02	-10.97	19.35	8.96
CHM	230.64	156.76	308.32	47.19
CHP	15.50	3.78	26.84	5.77
CIV	31.94	7.33	56.05	7.13
CMR	-8.72	-27.65	9.70	5.24
COD	56.23	35.19	77.93	8.33
COG	13.17	-7.57	31.36	3.38
COL	0.33	-13.81	13.24	10.39
CRB	4.14	0.74	7.72	1.43

CRI	6.24	-8.03	21.24	7.36
CUB	-2.63	-48.15	42.31	28.12
CYP	4.42	9.78	-1.46	2.82
CZE	18.26	-7.93	41.89	9.74
DEU	18.07	-0.51	36.04	11.40
DJI	-31.85	-40.88	-23.88	6.99
DNK	20.44	7.34	35.04	7.21
DOM	-7.47	-25.01	10.67	7.71
DZA	21.25	4.48	40.04	1.90
ECU	-0.98	-12.22	10.94	4.66
EGY	24.58	-1.69	48.68	7.33
ERI	24.25	11.00	36.61	9.56
ETH	33.85	23.51	43.51	7.65
FJI	-23.32	-31.05	-15.36	5.60
FNP	2.59	-17.55	20.23	4.44
FRP	32.56	22.04	41.97	7.06
GAB	-7.54	-26.34	11.75	5.54
GEO	32.36	-3.04	77.95	7.18
GHA	34.06	6.05	59.87	10.93
GIN	35.49	9.97	56.29	6.41
GMB	0.17	-13.61	14.80	0.99
GNB	64.01	31.71	92.86	6.24
GNQ	50.75	77.79	26.04	10.77
GRC	123.66	76.57	167.11	26.21
GSA	-4.48	-17.23	9.42	2.99
GTM	-9.55	-16.89	-2.36	10.37
HND	-5.89	-13.29	2.17	11.00
HRV	18.80	-3.73	43.11	8.74
HTI	-13.26	-29.89	1.69	4.02
HUN	57.49	19.21	93.26	19.02
IDN	35.07	6.63	64.08	6.93
IND	104.95	67.69	135.70	19.00
IRL	14.99	0.28	30.86	4.04
IRN	74.51	33.29	113.96	11.75
IRQ	-12.74	-28.15	2.11	8.26
ISL	16.34	1.00	32.52	3.56
ISR	48.78	34.64	59.90	7.85
ITP	89.17	58.03	122.58	19.37
JAM	-7.84	-27.18	8.85	4.37
JOR	9.89	0.17	20.80	2.31
JPN	81.74	73.33	90.21	16.03
KAZ	42.97	-1.27	86.65	6.94
KEN	3.28	-7.66	15.74	3.80
KGZ	50.09	7.95	95.68	10.74
KHM	59.24	43.38	76.10	2.66

KOR	118.53	84.35	147.68	24.53
LAO	53.80	39.72	67.40	4.70
LBN	25.91	7.89	43.98	4.70
LBR	31.06	7.36	51.15	5.24
LBY	10.59	-10.30	32.39	2.33
LKA	73.33	42.60	101.13	11.47
LSO	21.70	3.66	40.92	5.85
MDA	65.58	0.41	133.43	16.04
MDG	105.23	68.04	142.80	5.72
MEX	0.37	-14.81	13.69	17.82
MLI	37.81	21.13	54.18	2.50
MMR	86.66	51.25	110.50	18.06
MNG	-8.95	-16.49	-3.44	8.35
MOR	46.57	17.22	75.09	7.58
MOZ	13.20	-10.73	35.76	1.99
MRT	-10.11	-19.34	-0.43	2.78
MWI	68.74	50.66	84.44	26.12
MYS	-1.36	-11.15	7.02	1.92
NAM	-16.52	-30.06	-4.45	2.96
NER	13.51	5.82	19.44	2.42
NGA	21.93	7.46	37.08	2.94
NIC	-42.02	-49.00	-34.10	12.77
NLD	36.26	18.38	53.37	8.30
NOR	8.31	7.25	9.26	2.72
NPL	61.93	42.76	83.10	7.74
NZL	29.62	13.33	43.88	6.64
OAD	4.26	-0.81	8.97	2.29
OBN	45.81	29.24	60.92	12.12
OIO	7.05	1.30	12.00	2.01
OPO	-6.01	-9.06	-4.14	1.17
OSA	1.57	3.08	-0.09	0.77
PAK	9.32	-3.55	21.59	1.45
PAN	-30.82	-42.07	-19.53	6.34
PER	-3.99	-15.21	8.66	4.86
PHL	41.55	20.94	62.49	4.93
PNG	28.27	-2.00	52.79	18.17
POL	38.27	12.75	64.62	13.01
PRT	75.60	44.58	103.10	18.18
PRY	3.76	-12.21	16.44	13.44
RAP	0.39	-10.04	10.20	2.16
ROU	88.70	34.18	145.11	24.67
RUS	67.56	14.93	119.21	20.43
RWA	6.65	-2.71	15.77	5.91
SAU	-2.29	-17.20	11.46	1.56
SDN	23.42	10.21	36.52	3.91

SEN	15.99	-3.34	36.59	1.80
SLB	-39.40	-47.63	-30.01	3.03
SLE	43.79	4.40	83.97	5.72
SLV	-27.36	-39.48	-15.77	21.24
SOM	-36.24	-42.37	-29.91	6.16
SPP	24.08	25.09	23.32	7.25
SVK	-2.46	-32.10	29.37	6.98
SVN	35.15	10.23	60.17	15.27
SWE	4.55	-9.16	19.86	3.62
SWZ	-14.43	-34.69	5.20	5.26
SYR	12.87	-3.41	28.73	2.15
TCD	19.93	7.83	31.83	2.86
TGO	33.48	4.33	62.46	5.00
THA	44.68	22.40	60.52	5.54
TJK	13.00	-4.47	29.77	2.90
TKM	47.70	-1.43	96.30	3.26
TLS	10.23	3.44	16.64	0.77
TUN	37.95	13.68	59.45	4.73
TUR	55.38	32.14	77.28	10.43
TZA	12.14	-1.35	25.87	1.36
UGA	23.72	14.81	32.27	6.62
UKP	25.12	4.32	47.27	5.53
UKR	38.93	-32.09	101.31	14.78
URY	3.90	-14.99	22.07	6.82
USA	27.72	16.92	37.60	7.21
UZB	24.02	-24.25	69.62	6.45
VEN	-29.48	-42.56	-18.18	14.96
VNM	125.53	77.93	167.73	22.58
VUT	-19.45	-24.75	-14.58	1.84
YEM	-12.30	-21.45	-2.93	2.88
ZAF	-13.32	-20.18	-5.13	8.72
ZMB	-9.39	-17.79	1.77	3.44
ZWE	-15.49	-26.34	-5.30	5.41

Table A9.4: Climate-related deaths (in thousands) by region and country. Low and high values represent 95% confidence intervals, and CC SD represents the standard deviation of the main climate-change scenarios.

Region	Climate-related deaths (thousand)			
	mean	low	high	CC SD
Global	528.71	314.23	735.77	105.23
HIC	38.47	23.44	52.91	9.45
AFR_LMIC	27.69	11.72	43.73	3.74
AMR_LMIC	2.67	-5.87	10.88	5.52
EMR_LMIC	12.36	0.99	23.21	2.35
EUR_LMIC	14.34	1.76	26.41	3.77
SEA_LMIC	163.52	101.62	216.44	28.57
WPR_LMIC	264.27	177.72	354.41	53.29
AFG	1.70	1.21	2.17	0.61
AGO	1.47	1.60	1.32	0.16
ALB	0.24	0.12	0.34	0.04
ARG	0.21	-0.20	0.59	0.09
ARM	0.17	0.05	0.28	0.03
AUS	0.17	-0.02	0.37	0.15
AUT	0.22	0.07	0.36	0.11
AZE	0.40	0.75	0.06	0.03
BDI	0.51	0.30	0.70	0.05
BEN	0.37	0.05	0.70	0.03
BFA	0.73	0.49	0.98	0.08
BGD	9.95	6.77	13.29	0.97
BGR	0.03	-0.10	0.14	0.03
BLR	0.47	-0.14	1.02	0.22
BLT	0.40	0.19	0.60	0.13
BLX	0.39	0.21	0.57	0.11
BLZ	0.00	-0.01	0.00	0.00
BOL	-0.26	-0.39	-0.15	0.07
BRA	4.49	1.27	7.71	1.21
BTN	0.04	0.02	0.06	0.01
BWA	0.00	-0.03	0.02	0.00
CAF	-0.04	-0.10	0.02	0.01
CAN	1.13	0.95	1.28	0.28
CHL	0.07	-0.18	0.32	0.15
CHM	247.97	168.54	331.49	50.74
CHP	0.12	0.03	0.20	0.04
CIV	0.64	0.15	1.12	0.14
CMR	-0.19	-0.60	0.21	0.11
COD	4.94	3.09	6.84	0.73
COG	0.07	-0.04	0.16	0.02
COL	0.02	-0.67	0.64	0.50
CRB	0.01	0.00	0.02	0.00

CRI	0.03	-0.04	0.11	0.04
CUB	-0.02	-0.38	0.34	0.22
CYP	0.01	0.01	0.00	0.00
CZE	0.18	-0.08	0.40	0.09
DEU	1.20	-0.03	2.40	0.76
DJI	-0.03	-0.04	-0.02	0.01
DNK	0.10	0.04	0.18	0.04
DOM	-0.07	-0.24	0.10	0.07
DZA	0.81	0.17	1.52	0.07
ECU	-0.01	-0.19	0.17	0.07
EGY	2.23	-0.15	4.42	0.67
ERI	0.19	0.09	0.28	0.07
ETH	3.52	2.45	4.53	0.80
FJI	-0.02	-0.02	-0.01	0.00
FNP	0.01	-0.09	0.10	0.02
FRP	1.96	1.32	2.52	0.42
GAB	-0.01	-0.04	0.02	0.01
GEO	0.08	-0.01	0.20	0.02
GHA	1.02	0.18	1.80	0.33
GIN	0.34	0.10	0.54	0.06
GMB	0.00	-0.03	0.03	0.00
GNB	0.10	0.05	0.15	0.01
GNQ	0.05	0.07	0.02	0.01
GRC	1.16	0.72	1.57	0.25
GSA	0.00	-0.02	0.01	0.00
GTM	-0.16	-0.28	-0.04	0.17
HND	-0.05	-0.11	0.02	0.09
HRV	0.06	-0.01	0.15	0.03
HTI	-0.12	-0.27	0.02	0.04
HUN	0.43	0.14	0.69	0.14
IDN	7.95	1.50	14.53	1.57
IND	135.97	87.69	175.80	24.62
IRL	0.07	0.00	0.15	0.02
IRN	5.66	2.53	8.65	0.89
IRQ	-0.57	-1.27	0.09	0.37
ISL	0.01	0.00	0.01	0.00
ISR	0.49	0.35	0.60	0.08
ITP	4.63	3.01	6.36	1.01
JAM	-0.02	-0.06	0.02	0.01
JOR	0.10	0.00	0.20	0.02
JPN	7.62	6.84	8.41	1.49
KAZ	0.66	-0.02	1.32	0.11
KEN	0.16	-0.37	0.77	0.18
KGZ	0.24	0.04	0.45	0.05
KHM	0.76	0.55	0.97	0.03

KOR	4.71	3.35	5.86	0.97
LAO	0.33	0.25	0.42	0.03
LBN	0.10	0.03	0.18	0.02
LBR	0.23	0.05	0.37	0.04
LBY	0.08	-0.08	0.24	0.02
LKA	1.37	0.80	1.89	0.21
LSO	0.04	0.01	0.07	0.01
MDA	0.12	0.00	0.24	0.03
MDG	3.11	2.01	4.22	0.17
MEX	0.04	-1.65	1.52	1.98
MLI	0.81	0.45	1.15	0.05
MMR	3.27	1.93	4.17	0.68
MNG	-0.02	-0.05	-0.01	0.02
MOR	1.32	0.49	2.12	0.21
MOZ	0.35	-0.28	0.94	0.05
MRT	-0.04	-0.08	0.00	0.01
MWI	1.51	1.11	1.86	0.57
MYS	-0.04	-0.36	0.23	0.06
NAM	-0.04	-0.07	-0.01	0.01
NER	0.34	0.15	0.49	0.06
NGA	4.52	1.54	7.65	0.61
NIC	-0.21	-0.25	-0.17	0.06
NLD	0.54	0.27	0.79	0.12
NOR	0.05	0.04	0.05	0.02
NPL	2.26	1.56	3.03	0.28
NZL	0.14	0.06	0.20	0.03
OAO	0.00	0.00	0.01	0.00
OBN	0.61	0.39	0.82	0.16
OIO	0.02	0.00	0.03	0.00
OPO	0.00	0.00	0.00	0.00
OSA	0.01	0.02	0.00	0.00
PAK	1.88	-0.72	4.36	0.29
PAN	-0.12	-0.16	-0.08	0.02
PER	-0.10	-0.39	0.22	0.12
PHL	4.41	2.22	6.63	0.52
PNG	0.23	-0.02	0.42	0.15
POL	1.13	0.37	1.90	0.38
PRT	0.71	0.42	0.97	0.17
PRY	0.03	-0.09	0.12	0.10
RAP	0.01	-0.29	0.29	0.06
ROU	1.33	0.51	2.17	0.37
RUS	7.46	1.65	13.17	2.26
RWA	0.09	-0.04	0.22	0.08
SAU	-0.09	-0.71	0.47	0.06
SDN	1.28	0.56	2.00	0.21

SEN	0.24	-0.05	0.55	0.03
SLB	-0.03	-0.03	-0.02	0.00
SLE	0.32	0.03	0.61	0.04
SLV	-0.12	-0.18	-0.07	0.09
SOM	-0.34	-0.39	-0.28	0.06
SPP	1.06	1.11	1.03	0.32
SVK	-0.01	-0.15	0.14	0.03
SVN	0.06	0.02	0.11	0.03
SWE	0.04	-0.09	0.19	0.04
SWZ	-0.01	-0.04	0.01	0.01
SYR	0.32	-0.08	0.71	0.05
TCD	0.29	0.12	0.47	0.04
TGO	0.23	0.03	0.44	0.03
THA	2.69	1.35	3.65	0.33
TJK	0.07	-0.02	0.17	0.02
TKM	0.23	-0.01	0.46	0.02
TLS	0.01	0.00	0.02	0.00
TUN	0.39	0.14	0.61	0.05
TUR	4.06	2.36	5.67	0.77
TZA	0.73	-0.08	1.57	0.08
UGA	1.17	0.73	1.60	0.33
UKP	1.51	0.26	2.84	0.33
UKR	1.24	-1.02	3.22	0.47
URY	0.01	-0.04	0.06	0.02
USA	8.64	5.27	11.72	2.25
UZB	0.60	-0.61	1.75	0.16
VEN	-0.94	-1.36	-0.58	0.48
VNM	10.70	6.64	14.29	1.92
VUT	-0.01	-0.01	0.00	0.00
YEM	-0.43	-0.75	-0.10	0.10
ZAF	-0.60	-0.91	-0.23	0.39
ZMB	-0.16	-0.29	0.03	0.06
ZWE	-0.13	-0.23	-0.05	0.05

Table A9.5: Climate-related deaths (in thousands) by region and risk factor (FVC: fruit and vegetable consumption; MTC: red-meat consumption; UND: underweight; OVW: overweight; OBS: obesity).

Region	Climate-related deaths (thousands)					
	Total	FVC	MTC	UND	OVW	OBS
Global	528.71	533.55	-29.07	266.16	-34.94	-225.42
HIC	38.47	67.05	-9.48	10.01	-1.26	-27.94
AFR_LMIC	27.69	14.21	-1.11	53.45	-1.65	-37.68
AMR_LMIC	2.67	23.72	-2.78	5.97	-0.36	-24.45
EMR_LMIC	12.36	24.69	-0.98	10.67	-1.75	-20.92
EUR_LMIC	14.34	32.45	-4.01	1.33	-0.75	-15.67
SEA_LMIC	163.52	89.51	-1.27	146.79	-20.96	-56.88
WPR_LMIC	264.27	274.90	-9.39	37.64	-8.16	-39.91
AFG	1.70	0.46	-0.05	2.04	-0.24	-0.50
AGO	1.47	0.18	-0.03	2.39	-0.03	-1.04
ALB	0.24	0.35	-0.01	0.02	0.00	-0.12
ARG	0.21	1.20	-0.23	0.19	0.00	-0.97
ARM	0.17	0.28	-0.01	0.02	0.00	-0.14
AUS	0.17	1.32	-0.27	0.13	-0.02	-1.01
AUT	0.22	0.53	-0.18	0.05	-0.01	-0.16
AZE	0.40	0.92	-0.01	0.10	-0.02	-0.58
BDI	0.51	0.35	-0.01	0.59	-0.02	-0.43
BEN	0.37	0.18	-0.01	1.06	-0.04	-0.82
BFA	0.73	0.10	-0.07	0.99	-0.04	-0.22
BGD	9.95	1.92	-0.03	10.99	-1.61	-1.36
BGR	0.03	0.34	-0.06	0.05	-0.01	-0.31
BLR	0.47	1.31	-0.27	0.01	-0.04	-0.57
BLT	0.40	0.54	-0.12	0.00	0.00	-0.03
BLX	0.39	0.55	-0.10	0.03	0.00	-0.09
BLZ	0.00	0.01	0.00	0.00	0.00	-0.01
BOL	-0.26	0.18	-0.04	0.18	0.00	-0.59
BRA	4.49	10.24	-1.51	2.04	-0.18	-6.26
BTN	0.04	0.07	0.00	0.03	-0.01	-0.05
BWA	0.00	0.01	0.00	0.09	0.00	-0.10
CAF	-0.04	0.04	-0.02	0.20	-0.01	-0.24
CAN	1.13	2.55	-0.28	0.19	-0.03	-1.28
CHL	0.07	0.78	-0.09	0.11	0.00	-0.76
CHM	247.97	261.70	-8.54	23.63	-6.06	-31.50
CHP	0.12	0.31	-0.08	0.09	-0.02	-0.19
CIV	0.64	0.42	-0.02	1.51	-0.04	-1.25
CMR	-0.19	0.42	-0.02	0.84	-0.02	-1.45
COD	4.94	0.65	-0.02	6.98	-0.15	-2.56
COG	0.07	0.07	0.00	0.28	-0.01	-0.27
COL	0.02	1.80	-0.14	0.68	-0.11	-2.27
CRB	0.01	0.02	0.00	0.00	0.00	-0.02
CRI	0.03	0.24	-0.02	0.04	0.00	-0.24

CUB	-0.02	0.91	-0.05	0.18	-0.03	-1.09
CYP	0.01	0.05	0.00	0.02	0.00	-0.06
CZE	0.18	0.62	-0.20	0.03	0.00	-0.28
DEU	1.20	4.29	-1.29	0.52	-0.10	-2.22
DJI	-0.03	0.01	-0.01	0.03	0.00	-0.06
DNK	0.10	0.28	-0.07	0.05	-0.01	-0.15
DOM	-0.07	0.42	-0.03	0.11	-0.01	-0.58
DZA	0.81	1.63	0.00	0.83	-0.04	-1.64
ECU	-0.01	0.58	-0.03	0.20	-0.01	-0.78
EGY	2.23	5.65	-0.29	0.35	0.07	-3.80
ERI	0.19	0.01	0.00	0.32	-0.03	-0.11
ETH	3.52	0.31	-0.04	4.09	-0.17	-0.67
FJI	-0.02	0.01	0.00	0.00	0.00	-0.03
FNP	0.01	0.26	-0.07	0.04	-0.01	-0.20
FRP	1.96	2.99	-0.41	0.71	-0.07	-1.27
GAB	-0.01	0.05	0.00	0.07	0.00	-0.12
GEO	0.08	0.26	-0.03	0.00	0.00	-0.15
GHA	1.02	1.10	-0.04	2.15	-0.09	-2.16
GIN	0.34	0.33	-0.02	0.58	-0.03	-0.55
GMB	0.00	0.01	0.00	0.09	0.00	-0.10
GNB	0.10	0.02	0.00	0.19	-0.01	-0.10
GNQ	0.05	0.01	0.00	0.09	0.00	-0.05
GRC	1.16	1.39	-0.08	0.07	-0.01	-0.21
GSA	0.00	0.03	0.00	0.02	0.00	-0.05
GTM	-0.16	0.22	-0.01	0.17	0.00	-0.56
HND	-0.05	0.16	-0.01	0.06	-0.01	-0.26
HRV	0.06	0.22	-0.04	0.02	-0.01	-0.13
HTI	-0.12	0.15	-0.01	0.30	-0.01	-0.57
HUN	0.43	0.72	-0.14	0.03	-0.01	-0.19
IDN	7.95	11.10	-0.08	14.68	-3.08	-15.31
IND	135.97	70.23	-0.90	110.64	-15.17	-34.23
IRL	0.07	0.25	-0.06	0.02	0.00	-0.13
IRN	5.66	8.42	-0.01	0.55	-0.16	-3.24
IRQ	-0.57	1.28	-0.01	0.27	0.01	-2.17
ISL	0.01	0.02	0.00	0.00	0.00	-0.01
ISR	0.49	0.60	-0.02	0.02	0.00	-0.12
ITP	4.63	5.81	-0.75	0.17	-0.04	-0.54
JAM	-0.02	0.09	0.00	0.03	0.00	-0.14
JOR	0.10	0.23	0.00	0.02	0.00	-0.17
JPN	7.62	6.31	-0.49	4.64	-0.69	-2.16
KAZ	0.66	1.80	-0.25	0.10	-0.02	-1.04
KEN	0.16	0.65	-0.06	1.63	-0.07	-2.03
KGZ	0.24	0.51	-0.04	0.03	-0.02	-0.28
KHM	0.76	0.09	-0.01	0.88	-0.05	-0.15
KOR	4.71	5.02	-0.16	0.76	-0.16	-0.99

LAO	0.33	0.16	-0.01	0.35	-0.05	-0.12
LBN	0.10	0.18	0.00	0.01	0.00	-0.10
LBR	0.23	0.09	-0.01	0.52	-0.02	-0.36
LBY	0.08	0.33	0.00	0.03	0.00	-0.29
LKA	1.37	0.41	-0.01	2.08	-0.10	-1.02
LSO	0.04	0.01	0.00	0.13	0.00	-0.10
MDA	0.12	0.27	-0.03	0.01	-0.01	-0.14
MDG	3.11	0.41	-0.05	4.02	-0.29	-0.97
MEX	0.04	4.37	-0.40	0.61	0.02	-4.65
MLI	0.81	0.24	-0.02	1.25	-0.04	-0.62
MMR	3.27	1.58	-0.06	4.47	-0.49	-2.28
MNG	-0.02	0.07	0.00	0.01	0.00	-0.10
MOR	1.32	1.72	-0.01	0.15	-0.03	-0.59
MOZ	0.35	0.11	-0.06	1.91	-0.03	-1.54
MRT	-0.04	0.02	-0.01	0.12	0.00	-0.16
MWI	1.51	0.21	-0.01	2.02	0.00	-0.72
MYS	-0.04	0.74	-0.02	0.28	-0.05	-1.02
NAM	-0.04	0.02	-0.01	0.08	0.00	-0.13
NER	0.34	0.14	-0.08	0.69	-0.03	-0.36
NGA	4.52	3.40	-0.22	9.19	-0.26	-7.73
NIC	-0.21	0.04	0.00	0.04	0.00	-0.29
NLD	0.54	0.94	-0.11	0.20	-0.02	-0.47
NOR	0.05	0.22	-0.04	0.04	-0.01	-0.17
NPL	2.26	1.04	-0.07	2.22	-0.37	-0.60
NZL	0.14	0.35	-0.04	0.02	0.00	-0.20
OAD	0.00	0.01	0.00	0.00	0.00	-0.01
OBN	0.61	0.68	-0.03	0.01	0.00	-0.05
OIO	0.02	0.03	0.00	0.03	0.00	-0.04
OPO	0.00	0.00	0.00	0.00	0.00	0.00
OSA	0.01	0.03	0.00	0.04	-0.01	-0.04
PAK	1.88	4.82	-0.50	4.95	-1.19	-6.31
PAN	-0.12	0.10	-0.01	0.03	0.00	-0.24
PER	-0.10	0.65	-0.01	0.61	-0.03	-1.35
PHL	4.41	4.08	-0.23	6.13	-0.66	-4.99
PNG	0.23	0.56	-0.02	0.06	0.00	-0.46
POL	1.13	2.12	-0.48	0.13	-0.03	-0.65
PRT	0.71	1.04	-0.10	0.07	-0.01	-0.29
PRY	0.03	0.30	-0.05	0.10	-0.01	-0.32
RAP	0.01	0.68	0.00	0.06	0.01	-0.75
ROU	1.33	2.25	-0.23	0.17	-0.06	-0.86
RUS	7.46	15.54	-2.15	0.36	-0.23	-6.43
RWA	0.09	0.26	-0.01	0.25	-0.02	-0.42
SAU	-0.09	1.15	0.00	0.16	0.02	-1.44
SDN	1.28	1.37	-0.06	1.73	-0.18	-1.62
SEN	0.24	0.14	-0.01	0.99	-0.03	-0.84

SLB	-0.03	0.01	0.00	0.00	0.00	-0.03
SLE	0.32	0.09	0.00	0.94	0.00	-0.72
SLV	-0.12	0.10	-0.01	0.06	0.00	-0.28
SOM	-0.34	0.05	-0.05	0.07	0.00	-0.38
SPP	1.06	2.93	-0.51	0.47	-0.03	-1.78
SVK	-0.01	0.34	-0.10	0.02	-0.01	-0.26
SVN	0.06	0.13	-0.02	0.01	0.00	-0.06
SWE	0.04	0.42	-0.11	0.08	-0.02	-0.33
SWZ	-0.01	0.01	0.00	0.05	0.00	-0.08
SYR	0.32	0.89	0.00	0.05	0.02	-0.69
TCD	0.29	0.03	-0.02	0.64	-0.01	-0.34
TGO	0.23	0.05	-0.01	0.68	-0.03	-0.45
THA	2.69	3.15	-0.11	1.65	-0.14	-2.02
TJK	0.07	0.26	0.00	0.12	-0.03	-0.28
TKM	0.23	0.44	-0.02	0.05	-0.02	-0.24
TLS	0.01	0.00	0.00	0.03	0.00	-0.01
TUN	0.39	0.53	0.00	0.04	0.00	-0.20
TUR	4.06	5.29	-0.04	0.15	-0.02	-1.38
TZA	0.73	0.66	-0.06	2.45	-0.05	-2.31
UGA	1.17	0.73	-0.04	1.46	-0.02	-0.99
UKP	1.51	3.85	-0.53	0.30	-0.03	-2.11
UKR	1.24	4.32	-0.56	0.06	-0.18	-2.58
URY	0.01	0.14	-0.02	0.03	0.00	-0.14
USA	8.64	18.72	-2.75	0.81	0.07	-8.00
UZB	0.60	2.38	-0.19	0.22	-0.10	-1.88
VEN	-0.94	1.02	-0.11	0.19	0.02	-2.06
VNM	10.70	7.50	-0.56	6.30	-1.30	-1.48
VUT	-0.01	0.00	0.00	0.00	0.00	-0.01
YEM	-0.43	0.47	0.00	0.54	-0.06	-1.39
ZAF	-0.60	0.93	-0.07	0.29	0.00	-1.78
ZMB	-0.16	0.06	-0.01	0.49	-0.01	-0.68
ZWE	-0.13	0.03	-0.02	0.27	0.00	-0.40

Table A9.6: Climate-related deaths per capita (in deaths per million) by region and risk factor (FVC: fruit and vegetable consumption; MTC: red-meat consumption; UND: underweight; OVW: overweight; OBS: obesity).

Region	Climate-related deaths per capita (per million)					
	Total	FVC	MTC	UND	OVW	OBS
Global	77.99	78.71	-4.29	39.26	-5.15	-33.25
HIC	37.17	64.80	-9.16	9.67	-1.21	-27.00
AFR_LMIC	26.43	13.57	-1.06	51.00	-1.58	-35.96
AMR_LMIC	4.73	41.95	-4.92	10.56	-0.64	-43.24
EMR_LMIC	20.23	40.41	-1.61	17.47	-2.87	-34.23
EUR_LMIC	55.01	124.46	-15.36	5.08	-2.87	-60.10
SEA_LMIC	89.51	49.00	-0.69	80.35	-11.47	-31.14
WPR_LMIC	198.60	206.59	-7.06	28.29	-6.13	-29.99
AFG	40.77	11.12	-1.22	48.77	-5.85	-11.92
AGO	54.06	6.79	-1.19	88.21	-1.12	-38.39
ALB	88.10	130.90	-5.46	6.70	-1.65	-45.51
ARG	5.47	31.73	-5.98	5.10	-0.03	-25.69
ARM	80.95	136.33	-4.18	10.29	-1.13	-68.69
AUS	5.74	45.92	-9.44	4.57	-0.53	-35.08
AUT	29.04	68.50	-23.42	6.32	-1.43	-20.70
AZE	46.22	105.49	-1.17	11.79	-2.28	-66.50
BDI	44.42	30.13	-0.66	51.06	-2.08	-37.53
BEN	30.49	14.40	-0.67	86.24	-3.12	-66.87
BFA	32.15	4.24	-3.31	43.56	-1.58	-9.91
BGD	66.65	12.84	-0.22	73.61	-10.81	-9.11
BGR	4.82	64.40	-10.74	9.84	-1.99	-58.39
BLR	69.46	193.79	-39.80	1.40	-5.89	-83.90
BLT	83.52	113.06	-24.27	0.68	-0.51	-7.10
BLX	35.71	51.35	-9.72	2.81	-0.37	-8.29
BLZ	-6.15	29.51	-1.32	4.68	0.32	-40.20
BOL	-26.39	17.82	-3.64	17.93	-0.28	-59.24
BRA	24.25	55.30	-8.18	11.01	-1.00	-33.82
BTN	46.02	71.34	-2.23	36.04	-10.00	-55.66
BWA	-2.25	7.47	-2.00	46.10	-0.24	-53.62
CAF	-7.57	8.25	-5.02	40.28	-1.18	-47.97
CAN	29.52	66.50	-7.35	5.06	-0.79	-33.41
CHL	4.02	46.64	-5.13	6.65	0.07	-45.71
CHM	230.64	243.41	-7.94	21.98	-5.63	-29.30
CHP	15.50	41.33	-10.39	11.72	-2.04	-25.19
CIV	31.94	21.00	-0.90	75.61	-2.26	-62.63
CMR	-8.72	19.46	-0.87	38.64	-0.71	-66.66
COD	56.23	7.36	-0.26	79.46	-1.76	-29.13
COG	13.17	13.15	-0.78	53.98	-2.00	-52.13
COL	0.33	37.10	-2.81	13.96	-2.25	-46.77
CRB	4.14	11.65	-1.26	1.39	-0.02	-7.75

CRI	6.24	45.08	-2.96	7.71	-0.58	-44.24
CUB	-2.63	114.68	-6.57	23.01	-3.99	137.72
CYP	4.42	37.79	-1.62	13.41	-1.35	-43.47
CZE	18.26	64.26	-20.30	2.79	-0.41	-29.25
DEU	18.07	64.43	-19.40	7.81	-1.45	-33.31
DJI	-31.85	9.77	-6.69	31.56	-3.84	-58.77
DNK	20.44	54.97	-14.09	9.81	-1.77	-28.47
DOM	-7.47	43.16	-3.26	11.45	-1.02	-59.55
DZA	21.25	43.07	0.06	21.79	-1.11	-43.24
ECU	-0.98	38.05	-2.20	13.29	-0.48	-51.61
EGY	24.58	62.25	-3.16	3.85	0.72	-41.85
ERI	24.25	1.24	-0.56	41.56	-3.24	-14.52
ETH	33.85	2.97	-0.37	39.26	-1.65	-6.45
FJI	-23.32	19.00	-2.62	4.21	0.80	-45.32
FRP	2.59	52.71	-15.38	8.11	-2.53	-40.49
FRP	32.56	49.84	-6.75	11.89	-1.17	-21.17
GAB	-7.54	28.96	-2.32	43.05	-1.05	-76.98
GEO	32.36	98.62	-12.77	0.33	-1.73	-58.30
GHA	34.06	36.64	-1.22	71.64	-3.06	-71.87
GIN	35.49	34.54	-1.74	60.52	-3.11	-57.75
GMB	0.17	5.99	-1.12	44.92	-1.41	-47.95
GNB	64.01	13.09	-3.09	119.32	-3.56	-60.90
GNQ	50.75	11.78	-0.03	94.07	-1.88	-52.81
GRC	123.66	147.92	-8.48	7.02	-1.28	-22.60
GSA	-4.48	31.21	-1.50	17.10	-1.36	-51.00
GTM	-9.55	13.29	-0.48	10.27	-0.12	-33.18
HND	-5.89	19.54	-1.29	6.68	-0.61	-31.23
HRV	18.80	65.19	-12.61	7.32	-2.39	-39.41
HTI	-13.26	16.73	-0.98	33.26	-0.81	-63.20
HUN	57.49	98.03	-18.68	3.56	-0.99	-25.88
IDN	35.07	48.94	-0.36	64.72	-13.57	-67.51
IND	104.95	54.21	-0.69	85.40	-11.71	-26.42
IRL	14.99	49.72	-11.31	3.47	-0.54	-26.36
IRN	74.51	110.87	-0.10	7.19	-2.12	-42.62
IRQ	-12.74	28.49	-0.14	6.09	0.19	-48.26
ISL	16.34	44.19	-5.72	4.51	-0.85	-26.20
ISR	48.78	59.76	-1.74	2.33	-0.09	-11.72
ITP	89.17	111.82	-14.38	3.31	-0.71	-10.40
JAM	-7.84	44.52	-1.87	13.26	-0.43	-65.07
JOR	9.89	24.15	0.04	1.62	0.34	-17.42
JPN	81.74	67.60	-5.27	49.74	-7.35	-23.12
KAZ	42.97	118.00	-16.60	6.62	-1.55	-67.96
KEN	3.28	13.45	-1.29	33.40	-1.36	-41.79
KGZ	50.09	109.30	-7.64	5.42	-3.98	-59.30
KHM	59.24	6.72	-0.47	69.03	-3.81	-12.07

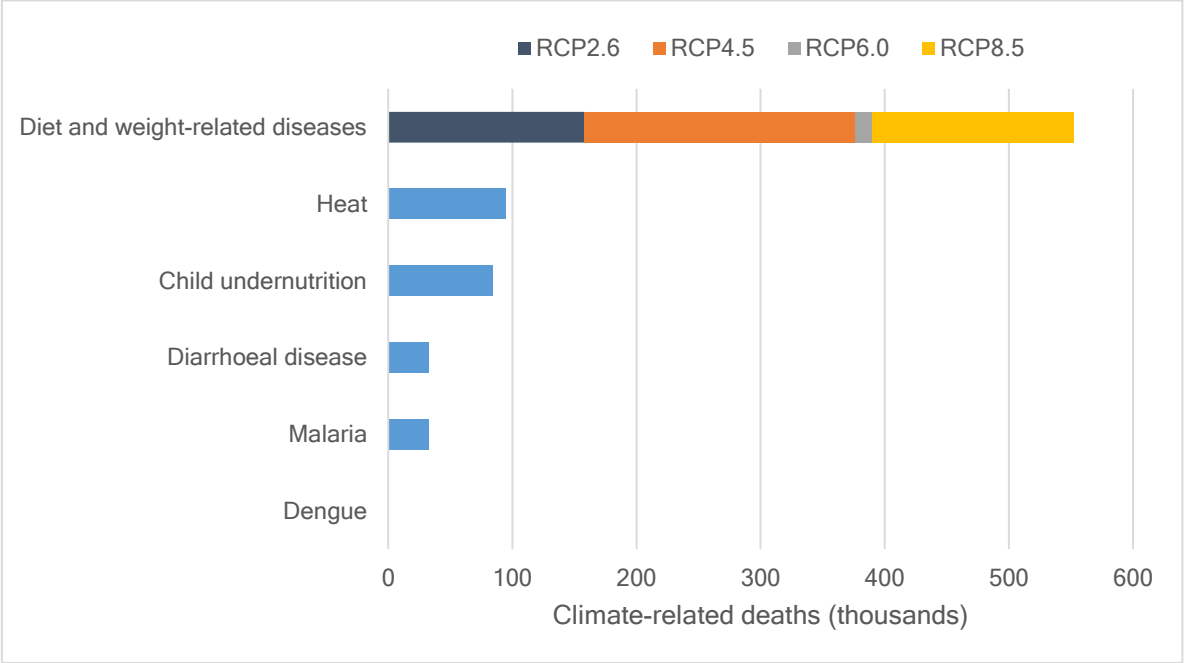
KOR	118.53	126.58	-3.93	19.21	-3.93	-25.04
LAO	53.80	25.06	-0.84	55.59	-8.36	-18.56
LBN	25.91	46.27	-0.32	2.74	0.00	-25.24
LBR	31.06	11.69	-1.12	72.00	-2.28	-49.21
LBY	10.59	44.78	0.02	4.09	0.41	-40.01
LKA	73.33	21.96	-0.53	111.50	-5.29	-54.78
LSO	21.70	5.68	-1.51	75.82	0.14	-58.42
MDA	65.58	149.72	-14.47	4.02	-3.45	-78.67
MDG	105.23	13.95	-1.76	136.24	-9.65	-32.83
MEX	0.37	39.36	-3.57	5.49	0.22	-41.85
MLI	37.81	11.22	-1.14	58.71	-1.73	-29.13
MMR	86.66	41.96	-1.62	118.38	-12.91	-60.43
MNG	-8.95	24.11	-0.96	4.09	0.22	-37.26
MOR	46.57	60.85	-0.29	5.37	-1.13	-20.99
MOZ	13.20	4.22	-2.12	72.49	-1.19	-58.38
MRT	-10.11	4.15	-2.34	27.43	-0.56	-38.32
MWI	68.74	9.70	-0.56	92.04	-0.22	-32.72
MYS	-1.36	22.72	-0.68	8.70	-1.48	-31.43
NAM	-16.52	8.00	-2.66	32.59	-0.61	-53.78
NER	13.51	5.31	-2.97	27.02	-1.15	-14.08
NGA	21.93	16.49	-1.07	44.55	-1.26	-37.50
NIC	-42.02	7.25	-0.74	7.19	0.30	-56.48
NLD	36.26	63.65	-7.62	13.44	-1.63	-31.63
NOR	8.31	40.09	-7.08	7.19	-1.32	-30.37
NPL	61.93	28.68	-1.99	60.85	-10.05	-16.34
NZL	29.62	75.09	-7.64	3.53	0.07	-42.46
OAD	4.26	10.03	-1.30	8.04	-0.42	-12.76
OBN	45.81	50.69	-2.51	0.96	-0.11	-3.49
OIO	7.05	13.16	-0.41	11.21	-0.86	-16.39
OPO	-6.01	6.37	-1.29	0.90	0.16	-12.29
OSA	1.57	4.68	-0.06	6.37	-2.30	-7.13
PAK	9.32	23.88	-2.50	24.53	-5.90	-31.29
PAN	-30.82	24.52	-3.38	8.61	-0.06	-61.42
PER	-3.99	25.51	-0.57	23.99	-1.08	-52.94
PHL	41.55	38.42	-2.17	57.75	-6.20	-47.03
PNG	28.27	69.53	-2.66	7.41	0.13	-57.36
POL	38.27	72.18	-16.18	4.44	-0.93	-22.16
PRT	75.60	110.25	-11.04	7.56	-0.79	-30.52
PRY	3.76	41.57	-7.13	14.19	-1.43	-44.84
RAP	0.39	23.84	-0.07	2.17	0.37	-26.17
ROU	88.70	150.35	-15.28	11.38	-4.00	-57.26
RUS	67.56	140.69	-19.42	3.27	-2.05	-58.16
RWA	6.65	18.47	-0.59	18.01	-1.13	-30.29
SAU	-2.29	27.98	-0.09	3.99	0.55	-35.15
SDN	23.42	25.10	-1.14	31.53	-3.29	-29.58

SEN	15.99	8.98	-0.94	65.81	-1.93	-55.86
SLB	-39.40	8.64	-1.18	4.21	0.82	-52.03
SLE	43.79	12.75	-0.43	129.92	-0.04	-98.96
SLV	-27.36	22.29	-1.15	12.76	-0.18	-61.73
SOM	-36.24	5.08	-5.65	7.65	-0.30	-41.19
SPP	24.08	66.57	-11.47	10.61	-0.78	-40.28
SVK	-2.46	73.48	-20.93	3.44	-2.21	-57.32
SVN	35.15	74.31	-11.40	6.04	-0.48	-34.37
SWE	4.55	43.38	-11.62	8.63	-2.44	-33.62
SWZ	-14.43	14.21	-3.68	53.73	0.21	-78.86
SYR	12.87	36.08	-0.10	2.06	0.63	-27.91
TCD	19.93	2.12	-1.23	43.16	-1.01	-22.72
TGO	33.48	7.76	-1.33	97.05	-4.64	-64.72
THA	44.68	52.32	-1.85	27.40	-2.30	-33.48
TJK	13.00	46.20	-0.68	20.88	-4.68	-50.68
TKM	47.70	92.37	-4.96	10.29	-4.96	-50.03
TLS	10.23	1.55	-0.59	24.00	-2.67	-11.49
TUN	37.95	51.69	-0.34	4.30	-0.35	-19.61
TUR	55.38	72.12	-0.57	2.06	-0.21	-18.75
TZA	12.14	10.93	-0.94	40.55	-0.85	-38.11
UGA	23.72	14.69	-0.80	29.56	-0.50	-20.12
UKP	25.12	64.18	-8.77	4.96	-0.49	-35.06
UKR	38.93	135.83	-17.66	1.80	-5.64	-81.05
URY	3.90	52.42	-6.77	11.85	-1.01	-53.97
USA	27.72	60.05	-8.83	2.61	0.22	-25.65
UZB	24.02	94.65	-7.37	8.66	-3.94	-74.90
VEN	-29.48	31.87	-3.60	5.82	0.50	-64.56
VNM	125.53	87.97	-6.55	73.91	-15.22	-17.39
VUT	-19.45	8.39	-2.48	2.89	0.34	-28.72
YEM	-12.30	13.40	-0.05	15.44	-1.75	-39.79
ZAF	-13.32	20.77	-1.51	6.39	0.00	-39.65
ZMB	-9.39	3.39	-0.69	29.90	-0.91	-41.02
ZWE	-15.49	3.29	-2.37	31.56	0.02	-46.39

Appendix A10: Research in context

Previous studies of the health impacts of climate change have either analysed complementary causes of death, or focused on the impacts of climate change on agriculture and health in terms of changes in food security and caloric availability.^{97,98} A recent WHO report integrated several analyses that quantified climate-related mortality caused by heat, coastal flooding, diarrhoeal disease, malaria, dengue and undernutrition in 2050.⁹⁹ Figure A10 adopts the WHO report’s central estimates and compares those to our results to illustrate the relevance of our focus.

Figure A10: Comparison of the number of climate-related deaths due to changes in dietary and weight-related risks in 2050, estimated in this study, with the number of climate-related deaths due to heat, coastal flooding, diarrhoeal disease, malaria, dengue, and child undernutrition in 2050, estimated for the WHO.⁹⁹ The number of climate-related deaths due to changes in dietary and weight-related risks are averaged across socio-economic pathways (see Table 2) and displayed for different representative concentration pathways (RCPs).



Appendix A11: Supplementary discussion

Several factors not included in this analysis could change future estimates of climate-related mortality from dietary and weight-related risk factors. They include explicit analyses of climate extremes, climatic impacts on fisheries and aquaculture, direct heat and water stress on livestock, climate impacts on the nutritional quality of foods, and longer-term analyses of climate impacts. Most of those factors can be expected to increase the climate-related health burden estimated in this study.

First, we did not include an explicit analysis of climate extremes in our assessment. Our modelling framework included climate and crop models with high regional and temporal resolution (up to daily time steps), but in assessing the biophysical yield shocks of climate change, all yield changes in a harvest year were summed and averaged across multiple different weather realizations.² This procedure focusses on the most likely impacts and provides less weight to less likely but potentially high impact events.¹⁰⁰

Second, we modelled the impacts of climate change on livestock production by accounting for climate-related changes in feed production, prices, and herd sizes.¹ However, these indirect impacts of climate change on livestock production do not account for some potential direct impacts, such as heat exposure and water availability. This suggests that the impacts of climate change on livestock production could be more responsive to climate change than found in this study. A greater climate-related reduction in red meat consumption would lead to a greater number of avoided deaths, which would reduce the total number of climate-related deaths.

Third, we chose to focus on the impacts of climate change on agriculture, which means we did not include fisheries and aquaculture in our assessment. Low consumption of seafood omega-3 fatty acids is an established risk factor for premature mortality.⁴⁷ Climate-related decreases in fish consumption are therefore likely to increase the climate-related health burden if reductions in seafood omega-3 fatty acids cannot be compensated for, e.g. by increased consumption of non-marine omega-3 fatty acids, such as alpha-linolenic ones.¹⁰¹

Fourth, we did not include climate-related changes in the nutritional content of foods in our assessment. Experiments have indicated that elevated concentrations of carbon dioxide could decrease the micro and macronutrient content of food crops.¹⁰² Such an effect would corroborate the negative health impacts found here, because a greater amount of e.g. fruits and vegetables would be needed to realize the same health benefits.

Fifth, the negative impacts of climate change are expected to be higher by the end of the century. Our analysis focussed on the year 2050, which is in line with recent impact assessment that have focussed on climate-related impacts on agriculture.^{95,99} Projections for the year 2050 are considered long term from an economic perspective, and longer projections are complicated by uncertainties of market condition and responses further into the future. However, climate models indicate that the negative yield impacts of climate change are relatively modest by mid-century, but increase more rapidly thereafter.^{36,97}

Finally, we want to highlight that our focus on the country level may hide important health inequalities and differentiated responses to dietary and weight-related risk factors on the local level. For example, we estimated that in many regions, the number of avoided deaths from climate-related reductions in overweight and obesity could exceed the number of deaths from climate-related increases in underweight. The estimates are based on analysing shifts in a country's weight distribution following changes in caloric availability – a method that follows current practice in assuming that all population groups are subject to weight changes.⁹⁹ However, food secure groups within a country might be better able, than food insecure groups, to adapt to changes in food prices associated with changes in caloric availability without necessitating weight changes. Food-secure groups in developing countries currently have a greater prevalence of overweight and obesity,¹⁰³ something that could lower the weight response to price changes. However, the opposite is the case for developed countries,¹⁰⁴ and it is expected that the association between socio-economic status and overweight changes from positive to negative

when income increases beyond a certain threshold.^{103,105} It is therefore not clear how our estimates for 2050 would change if we were able to resolve such differentiated impacts within countries and socio-economic groups.

References

- 1 Rosengrant MW, IMPACT Development Team. International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description. Washington, D.C.: International Food Policy Research Institute, 2012.
- 2 Robinson S, Mason-D'Croz D, Islam S, *et al.* The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) -- Model description for version 3. 2015; published online Oct.
- 3 Evenson RE, Rosengrant MW. Productivity Projections for Commodity Marketing Modeling. Paper presented at the final workshop of the International Cooperative Research Project on 'Projections and Policy Implications of Medium and Long-Term Rice Supply and Demand', organized by IFPRI, IRRI, and CCER, Beijing, China, April 23-26, 1995. 1995.
- 4 Evenson RE, Pray C, Rosengrant MW. Agricultural Research and Productivity Growth in India. IFPRI Research Report No. 109. 1999.
- 5 Hoogenboom G, Jones JW, Wilkens PW, *et al.* Decision Support System for Agrotechnology Transfer (DSSAT). ver. 4.5 [CD-ROM]. *Univ Hawaii Honol Hawaii* 2012.
- 6 Jones JW, Hoogenboom G, Porter CH, *et al.* The DSSAT cropping system model. *Eur J Agron* 2003; **18**: 235–65.
- 7 Edenhofer O, Pichs-Madruga R, Sokona Y, Farahani E, Kadner S. Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, 2014.
- 8 USDA. Commodity and Food Elasticities. Retrieved from <http://www.ers.usda.gov/Data/Elasticities/>. 1998.
- 9 GAMS. General Algebraic Modeling System (GAMS). GAMS, Washington, D.C. Retrieved from www.gams.com. 2012.
- 10 World Bank. Manufactures Unit Value Index. 2000. <http://data.worldbank.org/data-catalog/MUV-index>.
- 11 World Bank. Prospects Commodity Markets. 2012. <http://go.worldbank.org/4ROCCIEQ50>.
- 12 OECD-AMAD. Agricultural market Access Data Base. Retrieved from www.oecd.org/site/amad in 2013. 2010.
- 13 Narayanan BG, Walmsley TL. Global trade, assistance, and production: the GTAP 7 data base. *Cent Glob Trade Anal Purdue Univ* 2008.
- 14 International Trade Center. User Guide - Market Access Map: Making Tariffs and Market Access Barriers Transparent. Market Analysis Section, Division of Product and Market Development, International Trade Center, Geneva, December. 2006.
- 15 Boumellassa H, Laborde D, Mitaritonna C. A picture of tariff protection across the world in 2004: MAcMap-HS6, version 2. Intl Food Policy Res Inst, 2009.
- 16 OECD. Agricultural Policy Monitoring and Evaluation 2014: OECD Countries. 2014.
- 17 Jones PG, Thornton PK, Heinke J. Generating characteristic daily weather data using downscaled climate model data from the IPCC Fourth Assessment. Available at: <https://hc.app.box.com/shared/f2gk053td8>. 2009.
- 18 Hempel S, Frieler K, Warszawski L, Schewe J, Piontek F. A trend-preserving bias correction—the ISI-MIP approach. *Earth Syst Dyn* 2013; **4**: 219–36.
- 19 Piani C, Haerter JO, Coppola E. Statistical bias correction for daily precipitation in regional climate models over Europe. *Theor Appl Climatol* 2010; **99**: 187–92.

- 20 Weedon GP, Gomes S, Viterbo P, *et al.* Creation of the WATCH forcing data and its use to assess global and regional reference crop evaporation over land during the twentieth century. *J Hydrometeorol* 2011; **12**: 823–48.
- 21 You L, Wood-Sichra U, Fritz S, Guo Z, See L, Koo J. Spatial Production Allocation Model (SPAM) 2005 v2.0. Available from <http://mapspam.info>. 2014.
- 22 Müller C, Robertson RD. Projecting future crop productivity for global economic modeling. *Agric Econ* 2014; **45**: 37–50.
- 23 Priestley CHB, Taylor RJ. On the assessment of surface heat flux and evaporation using large-scale parameters. *Mon Weather Rev* 1972; **100**: 81–92.
- 24 Allen RG, Pereira LS, Raes D, Smith M, others. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *FAO Rome* 1998; **300**: D05109.
- 25 Chen Y-H, Paltsev S, Reilly JM, Morris JF, Babiker MH. The MIT EPPA6 Model: Economic Growth, Energy Use, and Food Consumption. MIT Joint Program on the Science and Policy of Global Change, 2015 <http://dspace.mit.edu/handle/1721.1/95765> (accessed Oct 18, 2015).
- 26 de Fraiture C. Integrated water and food analysis at the global and basin level. An application of WATERSIM. *Water Resour Manag* 2007; **21**: 185–98.
- 27 Rosegrant MW, Cai X, Cline SA. World water and food to 2025: dealing with scarcity. Intl Food Policy Res Inst, 2002.
- 28 Doorenbos J, Kassam AH. Yield response to water. *Irrig Drain Pap* 1979; **33**: 257.
- 29 KC S, Lutz W. The human core of the shared socioeconomic pathways: Population scenarios by age, sex, and level of education for all countries to 2100. *Glob Environ Change* 2014.
- 30 Chateau J, Dellink R, Lanzi E, Magne B. Long-term economic growth and environmental pressure: reference scenarios for future global projections. OECD. 2012.
- 31 O’Neill BC, Carter T, Ebi KL, *et al.* Meeting Report of the Workshop on The Nature and Use of New Socioeconomic Pathways for Climate Change Research. 2012. <http://hal.cirad.fr/hal-00801931/> (accessed Jan 17, 2015).
- 32 O’Neill BC, Kriegler E, Ebi KL, *et al.* The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. *Glob Environ Change* 2015.
- 33 O’Neill BC, Kriegler E, Riahi K, *et al.* A new scenario framework for climate change research: The concept of shared socioeconomic pathways. *Clim Change* 2014; **122**: 387–400.
- 34 Collins M, Knutti R, Arblaster JM, *et al.* Long-term climate change: projections, commitments and irreversibility. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 2013.
- 35 Van Vuuren DP, Edmonds J, Kainuma M, *et al.* The representative concentration pathways: an overview. *Clim Change* 2011; **109**: 5–31.
- 36 Rosenzweig C, Elliott J, Deryng D, *et al.* Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. *Proc Natl Acad Sci* 2014; **111**: 3268–73.
- 37 Jones CD, Hughes JK, Bellouin N, *et al.* The HadGEM2-ES implementation of CMIP5 centennial simulations. *Geosci Model Dev* 2011; **4**: 543–70.

- 38 Dufresne J-L, Foujols M-A, Denvil S, *et al.* Climate change projections using the IPSL-CM5 Earth System Model: from CMIP3 to CMIP5. *Clim Dyn* 2013; **40**: 2123–65.
- 39 Watanabe S, Hajima T, Sudo K, *et al.* MIROC-ESM 2010: Model description and basic results of CMIP5-20c3m experiments. *Geosci Model Dev* 2011; **4**: 845–72.
- 40 Bondeau A, Smith PC, Zaehle S, *et al.* Modelling the role of agriculture for the 20th century global terrestrial carbon balance. *Glob Change Biol* 2007; **13**: 679–706.
- 41 Food and Agriculture Organization of the United Nations. Food balance sheets: a handbook. Rome, 2001.
- 42 Hawkesworth S, Dangour AD, Johnston D, *et al.* Feeding the world healthily: the challenge of measuring the effects of agriculture on health. *Philos Trans R Soc Lond B Biol Sci* 2010; **365**: 3083–97.
- 43 Kearney J. Food consumption trends and drivers. *Philos Trans R Soc B Biol Sci* 2010; **365**: 2793–807.
- 44 Gustavsson J, Cederberg C, Sonesson U, Van Otterdijk R, Meybeck A. Global food losses and food waste: extent, causes and prevention. FAO Rome, 2011.
- 45 Cover TM, Thomas JA. Elements of information theory. John Wiley & Sons, 2012.
- 46 Murray CJ, Ezzati M, Lopez AD, Rodgers A, Vander Hoorn S. Comparative quantification of health risks: conceptual framework and methodological issues. *Popul Health Metr* 2003; **1**: 1.
- 47 Lim SS, Vos T, Flaxman AD, *et al.* A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *The Lancet* 2012; **380**: 2224–60.
- 48 Rockhill B, Newman B, Weinberg C. Use and misuse of population attributable fractions. *Am J Public Health* 1998; **88**: 15–9.
- 49 Ezzati M, Vander Hoorn S, Rodgers A, Lopez AD, Mathers CD, Murray CJ. Estimates of global and regional potential health gains from reducing multiple major risk factors. *The Lancet* 2003; **362**: 271–80.
- 50 Prospective Studies Collaboration, Whitlock G, Lewington S, *et al.* Body-mass index and cause-specific mortality in 900 000 adults: collaborative analyses of 57 prospective studies. *Lancet* 2009; **373**: 1083–96.
- 51 Berrington de Gonzalez A, Hartge P, Cerhan JR, *et al.* Body-Mass Index and Mortality among 1.46 Million White Adults. *N Engl J Med* 2010; **363**: 2211–9.
- 52 Micha R, Wallace SK, Mozaffarian D. Red and processed meat consumption and risk of incident coronary heart disease, stroke, and diabetes mellitus: a systematic review and meta-analysis. *Circulation* 2010; **121**: 2271–83.
- 53 Chen G-C, Lv D-B, Pang Z, Liu Q-F. Red and processed meat consumption and risk of stroke: a meta-analysis of prospective cohort studies. *Eur J Clin Nutr* 2013; **67**: 91–5.
- 54 Dauchet L, Amouyel P, Dallongeville J. Fruit and vegetable consumption and risk of stroke: a meta-analysis of cohort studies. *Neurology* 2005; **65**: 1193–7.
- 55 Dauchet L, Amouyel P, Hercberg S, Dallongeville J. Fruit and vegetable consumption and risk of coronary heart disease: a meta-analysis of cohort studies. *J Nutr* 2006; **136**: 2588–93.
- 56 WCRF/AICR. Food, Nutrition, Physical Activity, and the Prevention of Cancer: A Global Perspective. Washington, DC, USA: AICR, 2007.
- 57 Willett WC, Manson JE, Stampfer MJ, *et al.* Weight, weight change, and coronary heart disease in women: Risk within the ‘normal’ weight range. *JAMA* 1995; **273**: 461–5.

- 58 Asia Pacific Cohort Studies Collaboration. Body mass index and cardiovascular disease in the Asia-Pacific Region: an overview of 33 cohorts involving 310 000 participants. *Int J Epidemiol* 2004; **33**: 751–8.
- 59 Song Y-M, Sung J, Smith GD, Ebrahim S. Body Mass Index and Ischemic and Hemorrhagic Stroke A Prospective Study in Korean Men. *Stroke* 2004; **35**: 831–6.
- 60 Rexrode KM, Hennekens CH, Willett WC, et al. A prospective study of body mass index, weight change, and risk of stroke in women. *JAMA* 1997; **277**: 1539–45.
- 61 Calle EE, Rodriguez C, Walker-Thurmond K, Thun MJ. Overweight, obesity, and mortality from cancer in a prospectively studied cohort of U.S. adults. *N Engl J Med* 2003; **348**: 1625–38.
- 62 Reeves GK, Pirie K, Beral V, et al. Cancer incidence and mortality in relation to body mass index in the Million Women Study: cohort study. *BMJ* 2007; **335**: 1134.
- 63 Parr CL, Batty GD, Lam TH, et al. Body-mass index and cancer mortality in the Asia-Pacific Cohort Studies Collaboration: pooled analyses of 424,519 participants. *Lancet Oncol* 2010; **11**: 741–52.
- 64 Calle EE, Kaaks R. Overweight, obesity and cancer: epidemiological evidence and proposed mechanisms. *Nat Rev Cancer* 2004; **4**: 579–91.
- 65 Willett WC, Dietz WH, Colditz GA. Guidelines for healthy weight. *N Engl J Med* 1999; **341**: 427–34.
- 66 Chiolero A, Kaufman JS. Metabolic mediators of body-mass index and cardiovascular risk. *The Lancet* 2014; **383**: 2042.
- 67 Yusuf S, Hawken S, Ounpuu S, et al. Effect of potentially modifiable risk factors associated with myocardial infarction in 52 countries (the INTERHEART study): case-control study. *Lancet* 2004; **364**: 937–52.
- 68 Khaw K-T, Wareham N, Bingham S, Welch A, Luben R, Day N. Combined Impact of Health Behaviours and Mortality in Men and Women: The EPIC-Norfolk Prospective Population Study. *PLoS Med* 2008; **5**: e12.
- 69 Dam RM van, Li T, Spiegelman D, Franco OH, Hu FB. Combined Impact of Lifestyle Factors on Mortality: Prospective Cohort Study in US Women. *BMJ* 2008; **337**: 742–5.
- 70 Huxley RR, Ansary-Moghaddam A, Clifton P, Czernichow S, Parr CL, Woodward M. The impact of dietary and lifestyle risk factors on risk of colorectal cancer: a quantitative overview of the epidemiological evidence. *Int J Cancer J Int Cancer* 2009; **125**: 171–80.
- 71 Nechuta SJ, Shu X-O, Li H-L, et al. Combined impact of lifestyle-related factors on total and cause-specific mortality among Chinese women: prospective cohort study. *PLoS Med* 2010; **7**. DOI:10.1371/journal.pmed.1000339.
- 72 World Health Organization. Physical status: the use and interpretation of anthropometry. Report of a WHO Expert Committee. Technical Report Series No. 854. Geneva, Switzerland: World Health Organization, 1995.
- 73 Yusuf S, Reddy S, Ounpuu S, Anand S. Global burden of cardiovascular diseases: part I: general considerations, the epidemiologic transition, risk factors, and impact of urbanization. *Circulation* 2001; **104**: 2746–53.
- 74 Key TJ, Schatzkin A, Willett WC, Allen NE, Spencer EA, Travis RC. Diet, nutrition and the prevention of cancer. *Public Health Nutr* 2004; **7**: 187–200.
- 75 Sinha R, Cross AJ, Graubard BI, Leitzmann MF, Schatzkin A. Meat intake and mortality: a prospective study of over half a million people. *Arch Intern Med* 2009; **169**: 562–71.
- 76 Micha R, Michas G, Mozaffarian D. Unprocessed red and processed meats and risk of coronary artery disease and type 2 diabetes--an updated review of the evidence. *Curr Atheroscler Rep* 2012; **14**: 515–24.

- 77 Kaluza J, Wolk A, Larsson SC. Red meat consumption and risk of stroke: a meta-analysis of prospective studies. *Stroke J Cereb Circ* 2012; **43**: 2556–60.
- 78 Larsson SC, Wolk A. Red and processed meat consumption and risk of pancreatic cancer: meta-analysis of prospective studies. *Br J Cancer* 2012; **106**: 603–7.
- 79 WCRF/AICR. Continuous Update Project Report. Food, Nutrition, Physical Activity, and the Prevention of Pancreatic Cancer. 2012 [http:// www.dietandcancerreport.org](http://www.dietandcancerreport.org).
- 80 Song P, Lu M, Yin Q, *et al*. Red meat consumption and stomach cancer risk: a meta-analysis. *J Cancer Res Clin Oncol* 2014; published online March 29. DOI:10.1007/s00432-014-1637-z.
- 81 Zhu H, Yang X, Zhang C, *et al*. Red and Processed Meat Intake Is Associated with Higher Gastric Cancer Risk: A Meta-Analysis of Epidemiological Observational Studies. *PLoS ONE* 2013; **8**: e70955.
- 82 Choi Y, Song S, Song Y, Lee JE. Consumption of red and processed meat and esophageal cancer risk: Meta-analysis. *World J Gastroenterol WJG* 2013; **19**: 1020–9.
- 83 Salehi M, Moradi-Lakeh M, Salehi MH, Nojomi M, Kolahdooz F. Meat, fish, and esophageal cancer risk: a systematic review and dose-response meta-analysis. *Nutr Rev* 2013; **71**: 257–67.
- 84 Qu X, Ben Q, Jiang Y. Consumption of red and processed meat and risk for esophageal squamous cell carcinoma based on a meta-analysis. *Ann Epidemiol* 2013; **23**: 762–70.e1.
- 85 Huang W, Han Y, Xu J, Zhu W, Li Z. Red and processed meat intake and risk of esophageal adenocarcinoma: a meta-analysis of observational studies. *Cancer Causes Control CCC* 2013; **24**: 193–201.
- 86 WCRF/AICR. Research. Continuous Update Project Report. Food, Nutrition, Physical Activity, and the Prevention of Colorectal Cancer. 2011.
- 87 World Health Organization. Diet, nutrition and the prevention of chronic diseases: report of a joint WHO/FAO expert consultation. Diamond Pocket Books (P) Ltd., 2003.
- 88 Bazzano LA, He J, Ogden LG, *et al*. Fruit and vegetable intake and risk of cardiovascular disease in US adults: the first National Health and Nutrition Examination Survey Epidemiologic Follow-up Study. *Am J Clin Nutr* 2002; **76**: 93–9.
- 89 Rissanen TH, Voutilainen S, Virtanen JK, *et al*. Low Intake of Fruits, Berries and Vegetables Is Associated with Excess Mortality in Men: the Kuopio Ischaemic Heart Disease Risk Factor (KIHD) Study. *J Nutr* 2003; **133**: 199–204.
- 90 Genkinger JM, Platz EA, Hoffman SC, Comstock GW, Helzlsouer KJ. Fruit, Vegetable, and Antioxidant Intake and All-Cause, Cancer, and Cardiovascular Disease Mortality in a Community-dwelling Population in Washington County, Maryland. *Am J Epidemiol* 2004; **160**: 1223–33.
- 91 Agudo A, Cabrera L, Amiano P, *et al*. Fruit and vegetable intakes, dietary antioxidant nutrients, and total mortality in Spanish adults: findings from the Spanish cohort of the European Prospective Investigation into Cancer and Nutrition (EPIC-Spain). *Am J Clin Nutr* 2007; **85**: 1634–42.
- 92 Nagura J, Iso H, Watanabe Y, *et al*. Fruit, vegetable and bean intake and mortality from cardiovascular disease among Japanese men and women: the JACC Study. *Br J Nutr* 2009; **102**: 285–92.
- 93 Leenders M, Sluijs I, Ros MM, *et al*. Fruit and vegetable consumption and mortality: European prospective investigation into cancer and nutrition. *Am J Epidemiol* 2013; **178**: 590–602.
- 94 He FJ, Nowson CA, Lucas M, MacGregor GA. Increased consumption of fruit and vegetables is related to a reduced risk of coronary heart disease: meta-analysis of cohort studies. *J Hum Hypertens* 2007; **21**: 717–28.

- 95 Nelson GC, Valin H, Sands RD, *et al.* Climate change effects on agriculture: Economic responses to biophysical shocks. *Proc Natl Acad Sci* 2014; **111**: 3274–9.
- 96 Valin H, Sands RD, van der Mensbrugge D, *et al.* The future of food demand: understanding differences in global economic models. *Agric Econ* 2014; **45**: 51–67.
- 97 Porter JR, Xie L, Challinor A, *et al.* Food security and food production systems. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 2014: 485–533.
- 98 Smith KR, Woodward A, Campbell-Lendrum D, *et al.* Human health: Impacts, adaptation and co-benefits. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 2014: 709–54.
- 99 World Health Organization. Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s. Geneva, Switzerland: World Health Organization, 2014.
- 100 Sillmann J, Kharin VV, Zwiers FW, Zhang X, Bronaugh D. Climate extremes indices in the CMIP5 multimodel ensemble: Part 2. Future climate projections. *J Geophys Res Atmospheres* 2013; **118**: 2473–93.
- 101 Willett WC, Stampfer MJ. Current Evidence on Healthy Eating. *Annu Rev Public Health* 2013; **34**: 77–95.
- 102 Myers SS, Zanobetti A, Kloog I, *et al.* Increasing CO₂ threatens human nutrition. *Nature* 2014; **510**: 139–42.
- 103 Dinsa GD, Goryakin Y, Fumagalli E, Suhrcke M. Obesity and socioeconomic status in developing countries: a systematic review. *Obes Rev* 2012; **13**: 1067–79.
- 104 McLaren L. Socioeconomic status and obesity. *Epidemiol Rev* 2007; **29**: 29–48.
- 105 Monteiro CA, Moura EC, Conde WL, Popkin BM. Socioeconomic status and obesity in adult populations of developing countries: a review. *Bull World Health Organ* 2004; **82**: 940–6.