Health and Climate Change 4

Public health benefits of strategies to reduce greenhouse-gas emissions: food and agriculture

Sharon Friel, Alan D Dangour, Tara Garnett, Karen Lock, Zaid Chalabi, Ian Roberts, Ainslie Butler, Colin D Butler, Jeff Waage, Anthony J McMichael, Andy Haines

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National Centre for Epidemiology and Population Health, Australian National University, Canberra, ACT, Australia (S Friel PhD, A Butler BSc, Prof C D Butler PhD, Prof A J McMichael PhD)**; London School of Hygiene and Tropical Medicine, London, UK** (A D Dangour PhD, K Lock PhD, Z Chalabi PhD, Prof I Roberts PhD, Prof A Haines FMedSci)**; Food Climate Research Network, University of Surrey, Guildford, UK** (T Garnett MA)**; and London International Development Centre, London, UK** (Prof J Waage PhD)

Agricultural food production and agriculturally-related change in land use substantially contribute to greenhouse-gas emissions worldwide. Four-fifths of agricultural emissions arise from the livestock sector. Although livestock products are a source of some essential nutrients, they provide large amounts of saturated fat, which is a known risk factor for cardiovascular disease. We considered potential strategies for the agricultural sector to meet the target recommended by the UK Committee on Climate Change to reduce UK emissions from the concentrations recorded in 1990 by 80% by 2050, which would require a 50% reduction by 2030. With use of the UK as a case study, we identified that a combination of agricultural technological improvements and a 30% reduction in livestock production would be needed to meet this target; in the absence of good emissions data from Brazil, we assumed for illustrative purposes that the required reductions would be the same for our second case study in São Paulo city. We then used these data to model the potential benefits of reduced consumption of livestock products on the burden of ischaemic heart disease: disease burden would decrease by about 15% in the UK (equivalent to 2850 disability-adjusted life-years [DALYs] per million population in 1 year) and 16% in São Paulo city (equivalent to 2180 DALYs per million population in 1 year). Although likely to yield benefits to health, such a strategy will probably encounter cultural, political, and commercial resistance, and face technical challenges. Coordinated intersectoral action is needed across agricultural, nutritional, public health, and climate change communities worldwide to provide affordable, healthy, low-emission diets for all societies.

Introduction

The food system is a major contributor to global greenhouse-gas emissions. Greenhouse gases are produced at all stages in the system, from farming and its inputs through to food distribution, consumption, and the disposal of waste.[1] The latest Intergovernmental Panel on Climate Change report estimated that agriculture alone accounts for about 10–12% of global greenhouse-gas emissions, and emissions from this sector are expected to rise by up to half again by 2030.[2] Agriculturally-induced change in land use—such as deforestation, overgrazing, and conversion of pasture to arable land—presently accounts for a further 6–17% of global greenhouse-gas emissions.[3]

About half of all food-related greenhouse-gas emissions are generated during farming. Farm-stage emissions include nitrous oxide and methane from livestock, and carbon dioxide from agriculturally-induced change in land use, especially deforestation.[4,5] Nitrous oxide (from pasture land and arable land used to grow feed crops) and methane (from the digestive processes of ruminant animals such as cows and sheep) account for 80% of all agricultural greenhouse-gas emissions.[4] The emissions per unit of livestock product vary by animal type and seem to be higher in beef, sheep, and dairy farming than in pig and poultry farming (figure 1).[6] However, the ability of cattle and sheep to graze on land unsuited to other forms of farming, and the emissions associated with the production of feeds for pigs and poultry complicate the interpretation of this difference (panel 1). By 2030, rising demand for meat, especially in countries with transition economies,[8–10] is expected to drive up livestock production by 85% from that in 2000, which will substantially affect emissions.[11] Once foodstuffs leave the farm, the bulk of food-related emissions arise from use of fossil fuels.

The food system contributes to health benefits and harms through the availability, quality, and affordability of food. Animal foods are important sources of protein,

Key messages

- The agriculture sector contributes 10–12% of total greenhouse-gas emissions worldwide. Deforestation and other changes in land use contribute an additional 6–17% of global emissions. Production of foods from animal sources is the major contributor to emissions from the agricultural sector.
- Global demand for animal-source foods is projected to increase substantially over the next 30 years, especially in transition economies.
- Technological strategies within the food and agriculture sector, such as improved efficiency of livestock farming, increased carbon capture through management of land use, improved manure management, and decreased dependence on fossil-fuel inputs, are necessary but not sufficient to meet targets to reduce emissions.
- A combination of agricultural technological improvements and reduction in production of foods from animal sources could provide an effective contribution to meet national and global targets to reduce emissions.
- Concomitant reductions in consumption of livestock products in high-consumption populations could substantially benefit public health, for example via reductions in ischaemic heart disease.
- Policies to reduce emissions in the agricultural sector must ensure that the nutritional requirements of populations that might benefit from consumption of some foods from animal sources are not compromised.

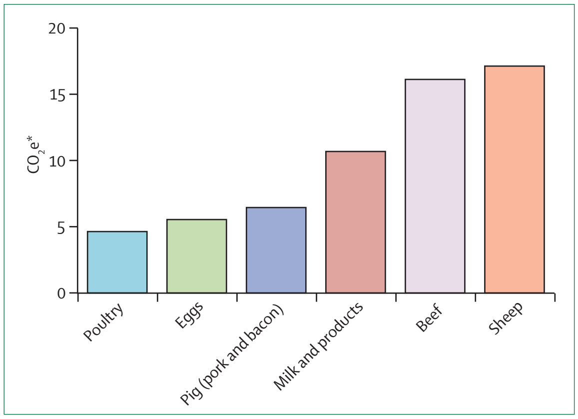

***Figure 1:* Estimates of total greenhouse-gas emissions for livestock products in the UK[6]†**
CO_2e=carbon dioxide equivalents. *Tonnes of CO_2e per tonne of carcass weight, 20 000 eggs (about 1 tonne), or 10 m^3 milk (about 1 tonne dry matter equivalent). †These estimates do not include additional emissions resulting from global change in land use that is associated with livestock production in the UK.

energy, and nutrients—such as iron, calcium, vitamin B12, and zinc[12]—especially for children and for undernourished populations in low-income countries,[13] but are also major sources of saturated fats in the human diet.[14] In all but the poorest countries, diets are becoming high in saturated fat and sugar, and low in fruit and vegetables.[15] In addition to other behaviours such as physical inactivity and tobacco use, such diets are a leading cause of non-communicable diseases, including cardiovascular disease, some cancers, and type 2 diabetes.[16]

We aim to describe strategies that could substantially reduce farm-stage greenhouse-gas emissions in the food and agriculture sector by 2030, to meet targets recommended by the UK Committee on Climate Change, and to show and quantify the major effects on public health.

Potential strategies to reduce emissions

From expert reports we identified four strategies to reduce greenhouse-gas emissions in the food and agriculture sector, with a focus on the livestock sector in view of the dominant contribution of processes in livestock production to agricultural emissions:[4] improved efficiency of livestock farming; increased carbon capture through management of land use; improved manure management; and decreased dependence on fossil-fuel inputs.[3,17,18] Reduced production and consumption of foods from animal sources in high-consumption populations[2,4,7,19–22] has also been proposed as a strategy. We did not consider other potentially important strategies including reduction of emissions from food transport, processing, and retailing since these are tackled best through measures to lower the carbon emissions from energy supplies and improve efficiencies. Nor did we assess the potential effect of decreasing food waste,[23] although we acknowledge that this strategy could contribute to reduced emissions.

***Panel 1:* Greenhouse-gas emissions from ruminant and monogastric animal production**

A shift from the production and consumption of livestock products of ruminant origin (beef, lamb, mutton, milk) to those of monogastric origin (pork, chicken, eggs) has been suggested as a measure to reduce greenhouse-gas emissions.[7] Indeed, emissions per kilogram of livestock product seem to be lower for monogastric than for ruminant animals (figure 1), at least partly because pigs and poultry have better feed-conversion efficiency than do ruminants, and because they do not emit enteric methane while digesting their feed. However, production of monogastric animals is inherently dependent on cereals and soy which could be more efficiently consumed by human beings directly, whereas cattle and sheep can subsist on marginal land that could not be used for arable production (often supplemented with food and agricultural byproducts). In so doing, cattle and sheep can make use of land that is unsuited to other forms of food production, thereby helping to avoid change in land use and reducing the competition between animals and human beings for cereals. Cattle and sheep grazing at the right stocking density on unploughed pasture can also help to maintain and even sequester carbon in the soil. Such resource efficiency by ruminants is not shared by pigs and poultry, except for cottage-scale pigs and poultry which are fed on kitchen scraps.

However, the global situation is complicated. Although ruminants can subsist on grassland, industrialised beef and dairy production relies on large inputs of cereals and oilseeds with accompanying methane emissions, thereby combining the disadvantages of monogastric and ruminant livestock production. Increasing demand for beef has led to the growth of cattle ranching and consequent deforestation in the Amazonian region and elsewhere. Furthermore, in developing countries, extensive grazing systems can lead to land degradation and the loss of soil carbon in regions where population pressures are high for human beings and livestock. Therefore, the merits of different livestock types to reduce emissions largely depend on the scale of demand and the system in which the animals are reared.

Pathways to health

We mapped the pathways from our selected strategies to reduce emissions to the most plausible nutrition-related health outcomes (figure 2). Technological strategies are necessary components of efforts to reduce emissions, but they will have little effect on health. By contrast, change in dietary intake of saturated fat from animal sources is a major pathway to population health. Consistent experimental and epidemiological evidence has linked intake of saturated fat with cardiovascular disease, largely because of the effect on serum cholesterol concentrations.[16,24] Cardiovascular disease is the world's leading cause of death, with the largest burden in countries of middle and low income.[25] Moreover, consumption of high-fat energy-dense diets is associated with increased risk of obesity,[16]

Correspondence to:
Dr Sharon Friel, National Centre for Epidemiology and Population Health, Australian National University, Canberra, ACT 0200, Australia
Sharon.friel@anu.edu.au

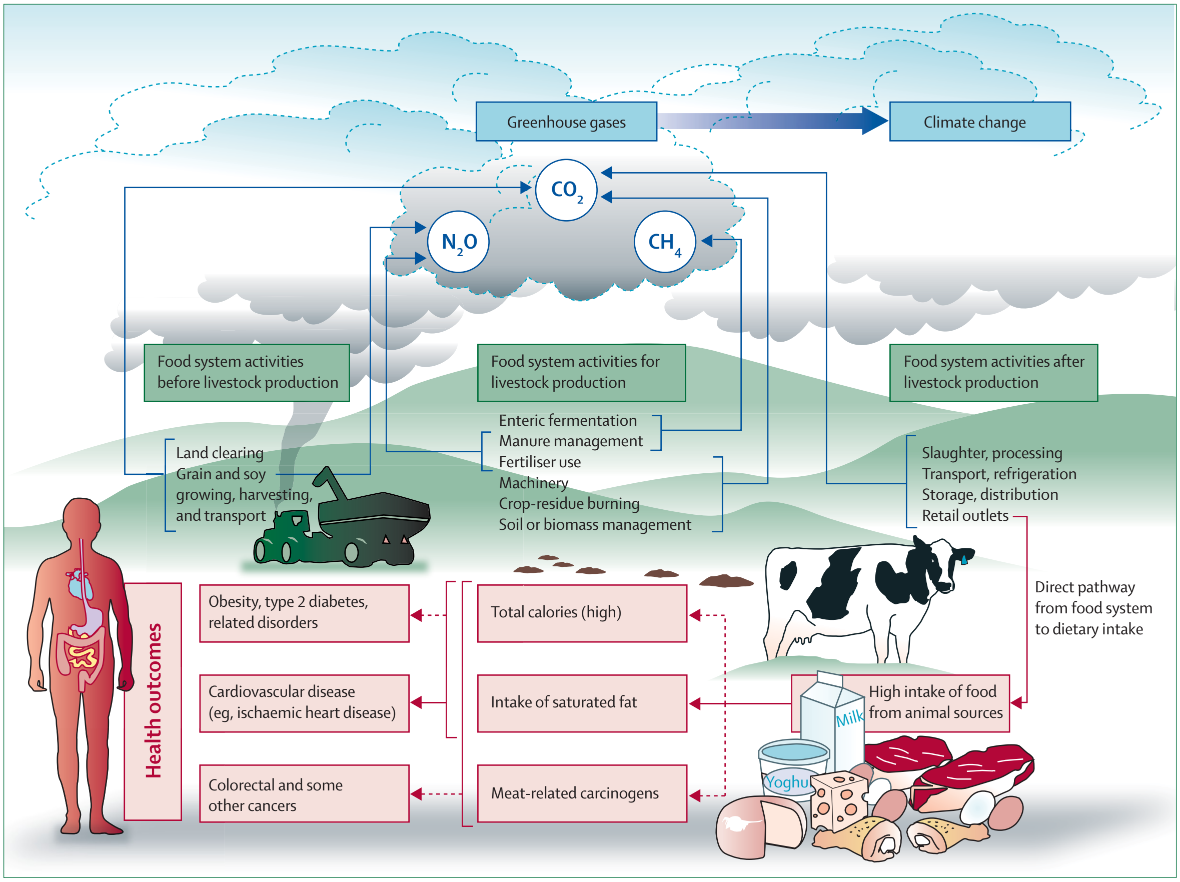

Figure 2: **Processes in the food and agriculture system that lead to greenhouse-gas emissions and population health outcomes**
Dotted lines indicate health outcomes that were not modelled in this study. CO_2=carbon dioxide. N_2O=nitrous oxide. CH_4=methane.

and, in the case of red meat, increased risk of colorectal cancer[26] and total mortality.[27]

Estimation of the effect on population health

To analyse the effect of reduced consumption of foods from animal sources on population health, we focused on changes in livestock production, the estimated shifts in intake of saturated fat and cholesterol at a population level, and the burden of cardiovascular disease, specifically ischaemic heart disease and stroke. We used Comparative Risk Assessment for modelling, as described in the first paper in this Series,[28] and briefly outlined in webappendix pp 1–2. We used case studies from the UK and São Paulo city, Brazil, to quantify the relation between the strategy to reduce emissions and the burden of ischaemic heart disease and stroke that would be attributable to decreased consumption of saturated fat and cholesterol. Both populations consume similar amounts of saturated fat; the UK is a high-income country that emits large quantities of greenhouse gases, and Brazil is an emerging economy with increasing greenhouse-gas emissions.

See Online for webappendix

The UK has good data available for both dietary intake and greenhouse-gas emissions. Estimates of average consumption of saturated fat and cholesterol in the UK, stratified by age and sex, are available from published data gathered for the nationally representative National Diet and Nutrition Surveys.[29–31] The surveys used 4-day[29] or 7-day[30,31] weighed dietary intake methods, and the data are separated into the source of dietary saturated fats by broad food category, enabling estimates of the proportion of total intake of saturated fat of animal origin. The source of saturated fat for some food categories (eg, cereal products such as cakes that might contain saturated fats from both animal and vegetable sources) was not known and was assumed to be of vegetable origin. Our estimates of intake of saturated fat from animal sources in the UK are therefore probably conservative.

Brazil, a country with a rapidly growing economy, is a mass producer and exporter of livestock products. The Brazilian population consumes substantial quantities of foods from animal sources and is undergoing a transition in its overall pattern of dietary intake.[32] Few data about greenhouse-gas emissions are available from the Brazilian agricultural sector, which restricted the scope of our modelling. Cattle ranching in combination with soy cultivation (at least partly for animal feed) are key causes of Amazonian deforestation, which substantially contributes to global emissions of greenhouse gases.[5,33] In

***Panel 2:* Strategies to reduce greenhouse-gas emissions from the UK food and agriculture sector**

The supply of food to UK consumers produces about 160 megatonnes of carbon dioxide equivalents ($MtCO_2e$), or 19% of the UK's total greenhouse-gas emissions.[1,35] These estimates include the embedded emissions from imported foods for human consumption and feedstuffs for UK livestock production, and exclude emissions from exported foods. In 1990, total emissions from the UK domestic agriculture sector were 55 $MtCO_2e$, a figure which by 2007 had reduced to 44 $MtCO_2e$, of which 36 $MtCO_2e$—about 80%—were due to the rearing of livestock.[36] About two-thirds of nitrous oxide emissions are attributable to livestock because of high nitrous oxide emissions from grasslands, which account for a high proportion of the UK's total agricultural land area.

In 2008, the UK Government agreed that by 2050, it would achieve an 80% reduction in total UK greenhouse-gas emissions from concentrations recorded in 1990, and has further committed to achievement of a 34% reduction by 2020.[37] These targets relate to emissions generated within UK borders only, and do not apply to the embedded emissions in the totality of goods and services consumed. To achieve the target for 2050, emissions from food and agriculture will need to decrease from concentrations recorded in 1990 by 50% by 2030, based on a proportionate decline in emissions between 2020 and 2050.

We have calculated the reductions in emissions that could be achieved by technological changes in livestock farming, and estimated the additional reductions in livestock production that would be needed to bridge the gap with the emissions target. We have assumed that agriculture contributes a proportional share to emissions reductions that is the same as for all other sectors. The potential reduction in emissions from the strategies is summarised in table 1.

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Strategy one: technological change

Technological change to reduce emissions in the UK agricultural sector includes increased efficiency, new technologies, and improved farm management, but estimates of its contribution to achievement of the target for 2020 vary widely: 3–13 $MtCO_2e$.[17,37,38] The mid-range ADAS estimate of 5 $MtCO_2e$ is used as the basis for our analyses.[38] In the absence of robust estimates of the UK potential to reduce emissions from agriculture by 2030, we made several assumptions. The potential to reduce emissions from technological means was taken at a starting point of 5 $MtCO_2e$ for agriculture in 2020, with 80% attributed to livestock (4 $MtCO_2e$).[4] We assumed that the greenhouse-gas mitigation achievable for 2020–30 would be equal to the estimated percentage improvement for 2007–20. For the livestock sector, the reduction for 2007–20 is expected to be 11·1% in $MtCO_2e$ (reduction of 4 $MtCO_2e$ from 36 $MtCO_2e$). A further 11·1% reduction for 2020–30 lowers livestock emissions to about 28 $MtCO_2e$. However, to reach the target of reduction from concentrations in 1990 by 50% by 2030, emissions from the livestock sector would need to be 22 $MtCO_2e$.

Strategy two: technological change and reduced livestock production

There is a gap of 6 $MtCO_2e$ between the reduction in emissions that can be achieved via technological strategies and the UK's target for 2030. To accommodate the projected UK population increase of 10% for 2010–30,[39] we have added 10% onto projected emissions in 2030 (assuming a proportionate increase in the amount of livestock products needed as projected from present UK consumption), resulting in emissions of 31 $MtCO_2e$ and an increase in the emissions gap to 9 $MtCO_2e$ (table 1). With the assumption that the emissions gap can be met by reduction of livestock production above that achieved by technological improvements in productivity, a reduction in livestock production of about 30% is needed by 2030. These reductions would be additional to technological changes. The lower the feasibility of technological and managerial changes, the greater the additional reductions in production that will be needed. Our burden of disease analysis assumes that this 30% reduction in livestock production will be matched by an equal reduction in the consumption of foods from animal sources.

the absence of nationally representative data about dietary intake for the Brazilian population, we obtained estimates of saturated-fat and cholesterol consumption for adults aged 20 years and older from the Household Health Survey,[34] which was undertaken in the largest city in Brazil, São Paulo. The Household Health Survey used a 24-h dietary recall method,[34] and unpublished data were provided on the intake of saturated fat and cholesterol from animal sources.

We used available data from the UK to estimate the potential of two strategies for the UK food and agriculture sector to attain a 50% reduction in greenhouse-gas emissions by 2030 (panel 2 and table 1). Strategy one assessed agricultural technological changes alone, and strategy two assessed decreased livestock production in addition to technological changes. Agricultural technological changes seem to be insufficient to meet reduction targets for emissions by 2030, and to meet the remaining emissions gap with strategy two, we estimated that an additional 30% reduction in all UK livestock production would be needed. In the absence of sufficient data about greenhouse-gas emissions from Brazil, we assumed for illustrative purposes that the same reduction in the proportion of livestock production would be needed for our case study in São Paulo city. Notably, if the food and agriculture sector in Brazil had to reduce emissions in proportion to its share of national emissions, the importance of change in land use in Brazil as a source of emissions suggests that our proposal could be quite

	$MtCO_2e$
In 1990[36]*	44
In 2007[36]	36
In 2020 after technological change[38]	32
In 2030†	
After technological change	28
After technological change and accounting for a 10% increase in UK population for 2010–30	31
Target for 2030 (50% of 1990 emissions)	22
Shortfall between target for 2030 and estimated emissions in 2030 (% of estimated emissions)	9 (~30%)

$MtCO_2e$=megatonnes of carbon dioxide equivalents. *Estimated as 80% of total agricultural greenhouse-gas emissions for 1990.[4,36] †Calculated with the assumption that the percentage reduction for 2020–30 will be the same as for 2007–20. ‡For simplicity, we make the assumption that the emission reductions achievable by overseas producers rearing livestock for UK consumption are similar to that achievable by technological changes in the UK. This assumption is realistic since most meat and dairy imports come from within the European Union and other developed countries in which management practices are similar. Strategies to reduce emissions focus on percentage reductions achievable through technological and consumption changes, rather than the achievement of an absolute figure in itself, and therefore the use of UK production-related reductions serve as a proxy for overall reductions achievable through technological change. We do not include the reductions in emissions from overseas producers in our calculations because of the complexities and scarcity of available data.

Table 1: **Potential reduction in greenhouse-gas emissions from technological changes in the UK livestock sector‡**

	Hazard ratio (95% CI)
Dietary intake of saturated fat*[41]	
Disability from ischaemic heart disease at >35 years	0·87 (0·77–0·97)
Death from ischaemic heart disease at >35 years	0·74 (0·61–0·89)
Serum cholesterol concentration†[42]	
Death from ischaemic heart disease	
40–49 years	0·45 (0·42–0·47)
50–59 years	0·57 (0·55–0·58)
60–69 years	0·68 (0·66–0·69)
70–79 years	0·79 (0·78–0·81)
80–89 years	0·85 (0·82–0·89)

*Per 5% reduced energy intake from saturated fatty acids and a concomitant increased intake of polyunsaturated fatty acids. †Per 1 mmol/L reduction in total serum cholesterol.

Table 2: **Risk of health outcomes from exposure to dietary saturated fat or from serum cholesterol concentration for use in burden of disease models for the food and agriculture sector**

conservative.[40] We acknowledge that Brazil is not committed to the same reductions in emissions as Annex 1 (industrialised) countries. There are uncertainties in estimation of the potential to reduce emissions in a complex living system, and in separation of livestock emissions from those generated by the agriculture sector as a whole.

We estimated the effect of a 30% decrease in livestock production on dietary intake of saturated fat and cholesterol from animal sources and on serum cholesterol concentration (webappendix p 3). We assumed that reductions in livestock production would result in declines of equal size in consumption of foods from animal sources, and specifically in dietary intake of saturated fat and cholesterol. This assumption is necessarily simplistic since various interconnected factors affect dietary intake, including international trade, waste, food prices, and sociocultural practices.

Hazard ratios from published meta-analyses[41,42] enabled quantification of the relation of intake of saturated fat and cholesterol with death or disability from ischaemic heart disease (table 2). We assumed isocaloric replacement of saturated fats with polyunsaturated fats. The Keys equation[43] was used to quantify the effect of changes in dietary intake of saturated fat and cholesterol on serum cholesterol concentration; consequently, we were also able to model the relation between the change in serum cholesterol concentration and death from ischaemic heart disease and stroke.[42] In both case studies, the analyses were based on average dietary intakes, and did not allow for individual, socioeconomic, or geographical variations that are known to exist in diets, or for underlying temporal changes in consumption that might take place by 2030.

We modelled the effect of a 30% reduction in intake of saturated fat and cholesterol from animal sources on the burden of ischaemic heart disease in the UK and São Paulo city (table 3). For the UK population, a 30% decrease in intake of saturated fats from animal sources could reduce the total burden from ischaemic heart disease by 15% in disability-adjusted life-years (DALYs), by 16% in years of life lost, and by 17% in number of premature deaths. From the model of disease burden associated with change in serum cholesterol concentration, reductions in ischaemic heart disease in the UK seemed to be lower than with the model of intake of saturated fats (5% in years of life lost, 4% in number of premature deaths).

In São Paulo city, a 30% reduction in intake of saturated fat from animal sources could reduce the total burden from ischaemic heart disease by 16% in DALYs, by 17% in years of life lost, and by 17% in number of premature deaths. Similar to results for the UK, reductions in the burden of disease in São Paulo city were lower with the model of change in serum cholesterol concentration than with the model of intake of saturated fat (7% in years of life lost, 6% in number of premature deaths). Last, we modelled the effect of change in serum cholesterol concentration on burden of disease due to stroke (cerebrovascular disease);[42] the prevalence of stroke is low in both the UK and São Paulo city, and the effect on burden of disease from stroke is small, but beneficial (webappendix p 4). Our estimates necessarily contain some uncertainty, and we have attempted to quantify the aspect of uncertainty that is associated with the health outcome from exposure to dietary saturated fat or change in serum cholesterol concentration (panel 3 and table 4).

Discussion

Urgent and substantial actions are needed to reduce greenhouse-gas emissions and thus stabilise the world's climate before the extent of climate change becomes obviously dangerous. Our combined strategy of agricultural technological change and decreased livestock production would reduce emissions in the agriculture sector. Moreover, our model indicated that the commensurate reductions in consumption of saturated fat and cholesterol from animal sources would substantially decrease deaths and disability caused by ischaemic heart disease. Association of exposure—saturated-fat intake and change in serum cholesterol concentration—with health outcome could have been responsible for the uncertainty in our estimates of the effect of the strategy to reduce emissions on disease burden. The estimated health benefits from decreased serum cholesterol concentration were smaller than were those from saturated-fat intake, and use of more nuanced data from cholesterol subclasses might have increased the estimated benefits. Whichever approach was used, overall the strategy improved public health.

We acknowledge that our analyses contain several limitations and assumptions, some of which could have resulted in underestimation of the effect of reduced emissions on public health. For example, health modelling was limited to pathways leading from consumption of livestock products to ischaemic heart disease, and we did not model the possible implications for other health outcomes, such as obesity and diet-related cancers.[26,44] Since we selected this specific health outcome, our modelling was undertaken for adults only. The case studies on which we based our model were set in countries where consumption of foods from animal sources is quite high; consequently, our results are not generalisable to countries with lower consumption of animal products. Our estimate of the potential reductions in emissions is subject to uncertainties and is likely to be an underestimate, since it is based on data from the UK only, and we did not include the potential savings in greenhouse-gas emissions that would accrue from livestock produced overseas for UK consumption. In other countries, especially developing countries, we expect that the potential for managerial approaches to reduce emissions might be greater than that recorded in our case studies.

Other limitations might have resulted in overestimation of health effects. First, we assumed that the reduction in national production of livestock would directly result in commensurate reductions in the intake of saturated fat and cholesterol from animal sources. This assumption is an oversimplification since livestock products are globally traded commodities, and reduced production in the UK and Brazil could only reduce national demand for consumption if such a change was not undermined by increased consumption of cheaply imported livestock products. Global actions are needed to achieve maximum benefits to public health in high-consumption populations. Second, we made no allowance for the different dietary proportions or total saturated-fat content of foods from animal sources, or for the contribution of different livestock to emissions. For example, since ruminant animals are an important source of methane, which has highly potent near-term warming potential (up to two orders of magnitude more potent than carbon dioxide in the first decade after release), reduction of products from such animals could be argued to be especially necessary.[7,45]

Third, we used data from two meta-analyses but in their investigation of the relation between saturated-fat consumption and ischaemic heart disease, Jakobsen and colleagues[41] recorded no modifying effect of age, probably because the statistical power was low, whereas the Prospective Studies Collaboration[42] reported age to be a strong modifier in their study of serum cholesterol concentration and ischaemic heart disease. Fourth, we modelled the effect of immediate and full implementation of our strategies, but in reality, the effects on public health will only become evident over time (ie, these are committed reductions that could take many years to be realised). Furthermore, the size of these effects might be modified in subsequent years because of changes in

	UK		São Paulo city, Brazil	
	Baseline (2010)	Change in disease burden and death (2030)	Baseline (2010)	Change in disease burden and death (2030)
Population				
Total in thousands*	61 367	NA	10 435	NA
Dietary intake of saturated fat[41]				
DALYs				
Total in thousands*	1183	–175	147	–23
Per million population†	19 270	–2850	14 090	–2180
Years of life lost				
Total in thousands*	1052	–165	127	–21
Per million population†	17 140	–2690	12 130	–2030
Premature deaths				
Total in thousands*	107	–18	8	–1
Per million population†	1750	–290	750	–130
Serum cholesterol concentration‡[42]				
Years of life lost				
Total in thousands*	1052	–55	127	–9
Per million population†	17 140	–900	12 130	–870
Premature deaths				
Total in thousands*	107	–4	8	–0·4
Per million population†	1750	–70	750	–40

Negative values show reductions in disease burdens. NA=not applicable. DALYs=disability-adjusted life-years. *Rounded to the nearest thousand; percentage reductions cannot be calculated accurately from rounded figures. †Rounded to the nearest ten; percentage reductions cannot be calculated accurately from rounded figures. ‡DALYs are not presented because the meta-analysis that we selected for our analysis did not provide information about the association between exposure and morbidity, and, therefore, years of life lost due to disability could not be calculated.

***Table 3:* Change in burden of ischaemic heart disease in 1 year from either a 30% reduction in dietary intake of saturated fat and cholesterol from animal sources, or the estimated effects of these dietary changes on serum cholesterol concentration**

Panel 3: **Uncertainty in burden of disease estimates**

We recognise the substantial uncertainty in our estimates of the health effects of strategies to reduce greenhouse-gas emissions. Therefore, we have attempted to quantify one aspect of this uncertainty: assessment of health outcome from exposure to intake of saturated fat or change in serum cholesterol concentration. The two models gave substantially differing results. To assess the relative contribution of structural uncertainty (ie, whether the pathway to health effects from direct intake of saturated fat is different from the effect of change in serum cholesterol concentration) and parameter uncertainty (ie, the accuracy of the mean estimate of exposure to health outcome compared with the true value) to these recorded differences, we repeated calculations with our models using the upper and lower 95% CIs of the published hazard ratios (table 2).

The upper and lower uncertainty bounds (table 4) suggest that although the mean reductions in years of life lost and number of premature deaths differed between the two models, the lower uncertainty bound from the model of saturated-fat intake was similar to the upper uncertainty bound of the model of change in serum cholesterol concentration for the UK. Furthermore, in São Paulo city the lower and upper uncertainty bounds of the two models overlapped. We conclude that the difference between the estimates provided by the two models is largely compatible with parameter uncertainty in the hazard ratios, but does not exclude structural uncertainty. The wide 95% CI for the model of dietary saturated-fat intake probably indicates the difficulty in accurate estimation of fat consumption in free living populations.

	UK	São Paulo city, Brazil
Years of life lost (total in thousands*)		
Dietary intake of saturated fat	165 (67–257)	21 (9–33)
Serum cholesterol concentration	55 (50–60)	9 (9–10)
Premature deaths averted (total in thousands*)		
Dietary intake of saturated fat	18 (7–28)	1 (0·5–2)
Serum cholesterol concentration	4 (4–5)	0·4 (0·4–0·5)

Data are mean (lower–upper uncertainty bounds). *Rounded to the nearest thousand.

Table 4: **Analysis of variability in mean estimates of reduction in burden of ischaemic heart disease from a 30% reduction in dietary intake of saturated fat and cholesterol from animal sources, and the estimated effects of these dietary changes on serum cholesterol concentration**

population structure and the background frequency of cardiovascular disease, which is declining in the UK[46] and Brazil[47] because of several factors including other public health and health-care interventions. However, for much of the world, occurrence of cardiovascular disease is rising,[25] and so strategies to reduce emissions might have even greater benefit for population health in such countries. Last, we did not account for the emissions of substitute foods in our calculation of reduced emissions from reduced consumption of livestock products. Our model is based on replacement of saturated fat with polyunsaturated fats. Generally, plant-based diets are high in polyunsaturated fats and have a lower greenhouse-gas burden than do foods from animal sources,[48,49] but some plants are also important sources of saturated fats (eg, palmitic acid in palm oil). Our analysis also made no allowance for the varying amounts of different saturated fatty acids in meat and dairy products. Whereas saturated fats raise overall serum cholesterol concentration, individual saturated fatty acids have contrasting effects.[50]

Despite these limitations, we have shown that a strategy to reduce production and consumption of foods from animal sources would help to prevent dangerous climate change from greenhouse-gas emissions and benefit the health of adults in countries consuming high amounts of animal products. This strategy has several policy implications for trade, agriculture, and health. An important challenge in public health is to balance the need for adequate population intake of animal-source protein and essential nutrients with reduced consumption of saturated fat. Almost a billion people have protein-energy undernutrition, most of whom are also undernourished in micronutrients, especially iron and zinc. Adequate protein, energy, iron, and zinc can be obtained from a plant-based diet.[51,52] However, the consumption of a small amount of animal-source foods per day in low-consumption populations could help to alleviate the burden of undernutrition.[53] At present, agricultural production is mismatched with the provision of a diet that is balanced in terms of foods from plant and animal sources. Globally, production per head of energy, fats, proteins, and micronutrients has increased and is sufficient to meet global population needs,[54] but the benefits have not been distributed evenly across countries and regions.[55] A wide range of factors affect the supply and demand for animal-source foods; some policy levers offer potential approaches to change consumption patterns in populations (panel 4).

A 30% reduction in adult consumption of livestock products in high-consumption countries results in intake of saturated fat that falls well within existing distributions of population intake[73] and is therefore realistic from a dietary perspective. Our findings have important implications for agriculture. Although reduced livestock production and consumption will have social, health, and environmental advantages, these benefits are affected by geographical, social, and economic contexts. For example, ruminant livestock in upland and marginal areas can help to maintain and build the carbon-sequestering properties of soil. Where grazing cattle are reared without use of feed inputs or additional fertiliser, and at low stocking densities, carbon sequestering can outweigh methane and nitrous oxide emissions.[74] Intensive agricultural methods have

Panel 4: **Potential policy levers to reduce consumption of foods from animal sources**

The food production system is a complex interaction of global, national, and local factors that can affect supply and demand with respect to foods from animal sources. Various policy levers can affect food supply: direct investment by transnational food corporations; trade arrangements affecting food imports, exports, and domestic production; agricultural policy; food processing and procurement; and retail systems.[56–59]

Food pricing, food marketing and labelling, and community-level interventions affect dietary demands of consumers.[60–63] Evidence from several countries suggests that a comprehensive range of intersectoral policies that combine such interventions with nutritional education can change the type of dietary fats consumed. In Finland, such an approach may have changed patterns of consumption, including the type of dietary fats, and reduced mortality due to ischaemic heart disease by 65%.[64] Regulatory policies in Canada, Denmark, and Mauritius, including those on food labelling and composition, have improved the fat content of foods, with benefits to health.[65–67] Preliminary work in the UK suggests that taxation of unhealthy foods could produce modest changes in diet,[63,68] and the Danish Academy of Technical Sciences has recommended that healthy foods be subsidised by 20% and unhealthy foods be taxed by 30%.[69]

New policy initiatives are emerging with a focus on the environmental benefits of dietary change. Sweden produced dietary guidelines in 2009 recommending that citizens eat meat less often and in reduced quantities, to decrease greenhouse-gas emissions,[70] and the city council of Ghent in Belgium has proclaimed a meat-free day each week.[71] Although inclusion of environmental concerns in dietary guidelines and social marketing will probably have little effect on behavioural change, as part of a comprehensive policy approach to sustainable and healthy dietary behaviours, they could be a useful advance to link health and climate-change agendas.[72]

resulted in increased atmospheric ammonia release, which has boosted forest growth in temperate and tropical regions (carbon sinks). However, curbing ammonia emissions from agriculture, even radically, would have little effect on the global carbon sink.[75] Changes in land use that disrupt the soil, such as ploughing for arable production, cause release of stored carbon into the atmosphere, and livestock production can therefore prevent land from being used for other potentially carbon-releasing purposes.[76] Further, in many geographical regions (including the uplands in the UK) no form of food production other than livestock rearing is feasible at present. Livestock rearing also has a key cultural and economic role in many parts of the world and is estimated to create livelihoods for a billion of the world's poor people.[12,13]

By contrast, excessive livestock production to meet growing demand has created problems of soil degradation, biological impoverishment, and, through overgrazing and intensive feed production, a loss in the soil's ability to sequester carbon.[13] The cultivation of crops for biofuel production is an emerging issue of relevance to livestock production. Biofuel production places additional pressure on land, but conversely, the refining of oil or starch grains to produce biodiesel or ethanol can generate protein rich byproducts that can be used to feed animals.[77–79] Furthermore, climate change generally affects livestock production and agriculture via water and heat stress, and change in the spread of pests, disease, and infections.[80]

Reduction of greenhouse-gas emissions in the food and agricultural sector could help to prevent climate change and reduce the burden of ischaemic heart disease. Formulation of appropriate national and international policies that recognise both the benefits of reduced livestock production in high-consumption countries and the need for more equitable distribution of these products remains an important global challenge. Such policies will need intersectoral actions and good global governance to succeed.

Contributors

ADD, SF, TG, AH, IR, and JW led, and CDB and AJM contributed to, the conceptual development of the report. TG developed the greenhouse-gas mitigation scenarios. ADD led, and KL contributed to, the nutrition and health analysis. ZC did the modelling. SF wrote the first draft of the report. All authors contributed to the intellectual guidance, analysis, and subsequent drafts of the report.

Conflicts of interest

We declare that we have no conflicts of interest.

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