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Food, livestock production, energy, climate change, and health

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Food provides energy and nutrients, but its acquisition requires energy expenditure. In post-hunter-gatherer societies, extra-somatic energy has greatly expanded and intensified the catching, gathering, and production of food. Modern relations between energy, food, and health are very complex, raising serious, high-level policy challenges. Together with persistent widespread under-nutrition, over-nutrition (and sedentarism) is causing obesity and associated serious health consequences. Worldwide, agricultural activity, especially livestock production, accounts for about a fifth of total greenhouse-gas emissions, thus contributing to climate change and its adverse health consequences, including the threat to food yields in many regions. Particular policy attention should be paid to the health risks posed by the rapid worldwide growth in meat consumption, both by exacerbating climate change and by directly contributing to certain diseases. To prevent increased greenhouse-gas emissions from this production sector, both the average worldwide consumption level of animal products and the intensity of emissions from livestock production must be reduced. An international contraction and convergence strategy offers a feasible route to such a goal. The current global average meat consumption is 100 g per person per day, with about a ten-fold variation between high-consuming and low-consuming populations. 90 g per day is proposed as a working global target, shared more evenly, with not more than 50 g per day coming from red meat from ruminants (ie, cattle, sheep, goats, and other digastric grazers).

Introduction

Food provides energy and nutrients, and its acquisition requires the expenditure of energy. In post-hunter-gatherer societies, with progressively increasing inputs of extra-somatic energy, the scale of catching, gathering, and producing food has been greatly expanded and methods intensified. Today, relations between energy, food, and health have become complex and multifaceted, raising serious policy concerns at national and international levels.

Substantial and widespread public-health problems of under-nutrition and over-nutrition exist—often coexisting within the same population. Meanwhile, the world's agricultural sector, especially livestock production, accounts for about a fifth of total greenhouse-gas emissions, thus contributing to climate change and its effects on health, including on regional food yields. Policy responses to the connections between food production, energy, climate, and health should include countering the world's rapidly increasing consumption of meat, which poses health risks by exacerbating climate change and by direct contribution to the causation of certain diseases. These linkages are explored in this paper, and recommendations for policy are made.

The story of world food production and associated changes in population health over recent centuries comprises both good and bad news. There is much good news: food production capacity has increased greatly; maternal and child nutrition in high-income populations and groups has improved; health and life expectancies have increased, at least partly because of nutritional gains; and refrigeration, transport, and open markets have increased year-round access to healthy foods for many populations.

Meanwhile, health risks are also accruing: the expansion of food production is depleting land cover and biodiversity, with diverse consequences for human wellbeing and health; major elemental cycles are being disrupted (eg, fertiliser use has vastly increased the concentration of bioactive nitrogen compounds in the global environment); industrial food refining, marketing, and over-consumption increase the risks of some non-communicable diseases; and fossil fuel inputs to modern food systems, together with other

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Key messages

- Greenhouse-gas emissions from the agriculture sector account for about 22% of global total emissions; this contribution is similar to that of industry and greater than that of transport. Livestock production (including transport of livestock and feed) accounts for nearly 80% of the sector's emissions
- Methane and nitrous oxide (which are both potent greenhouse gases and closely associated with livestock production) contribute much more to this sector's warming effect than does carbon dioxide
- Halting the increase of greenhouse-gas emissions from agriculture, especially livestock production, should therefore be a top priority, because it could curb warming fairly rapidly. However, livestock production is projected, on current trends, to increase substantially over the next four decades, mainly in countries of low or middle income
- Available technologies for reduction of emissions from livestock production, applied universally at realistic costs, would reduce non-carbon dioxide emissions by less than 20%. We therefore advocate a contraction and convergence strategy to reduce consumption of livestock products, mirroring the widely supported strategy proposed for greenhouse-gas emissions in general. Contraction of consumption in high-income countries per head would then define the lower, common, ceiling to which low-income and middle-income countries could also converge

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- Assuming a 40% increase in global population by 2050 and no advance in livestock-related greenhouse-gas reduction practices, global meat consumption would need to fall to an average of 90 g per person per day just to stabilise emissions from this sector. Such a decrease would require a substantial reduction of meat consumption in industrialised countries and constrained growth in demand in developing countries, especially of red meat from ruminant (methane-producing) animals
- A substantial contraction in meat consumption in high-income countries should benefit health, mainly by reducing the risk of ischaemic heart disease (especially related to saturated fat in domesticated animal products), obesity, colorectal cancer, and, perhaps, some other cancers. An increase in the consumption of animal products in low-intake populations, towards the proposed global mean figure (convergence), should also benefit health
- The resultant gains in health and environmental sustainability should help to offset any (initial) discomforts from restrictions on some popular foods and altered dietary customs. Replacing ruminant red meat with meat from monogastric animals or vegetarian-farmed fish would reduce methane production and lower the pressures on wild fisheries as sources of fishmeal for aquaculture
- Climate change will, itself, affect food yields around the world unevenly. Although some regions, mostly at mid-to-high latitude, could experience gains, many (eg, in sub-Saharan Africa) are likely to be adversely affected, with impairment of both nutrition and incomes. Compensating vulnerable populations for this and other climate-mediated harm caused by other populations should be an important element of global climate change policy
- Global population growth is continuing, although slowing. The eventual peak size is not predetermined: it can be lowered by education, leadership, and wider contraceptive availability. Slower population growth will help achieve the Millennium Development Goals and will limit population size, climate change, and the environmental effects of food production

aspects of crop production and animal husbandry, contribute substantially to greenhouse-gas emissions.

The other great deficit in relation to the interaction of food systems, nutrition, and health is the persistence of hunger and macronutrient under-nutrition in about 13% of the world's population (850 million people). Although this topic is beyond the scope of this paper, we note that today's combination of a globalised economic system with persistent economic disparities between rich and poor, and the depletion of the environmental resource base for food production on land and at sea, militates against reduction of this basic public-health problem.

We review the history of human beings' quest for food, noting how it has brought health gains from food abundance and health losses from chronic or intermittent food shortages and dietary imbalances. We review the prospects for food production, environmental sustainability, and health in view of human-induced adverse changes in the world's environment, especially climate change. We conclude by identifying the two most important contemporary policy challenges related to our theme: reducing the contribution of food production and distribution systems (especially those for meat) to global

Key indicators

Strategy for reduction of agriculture-related greenhouse-gas emissions

National and international climate change policies all accept a target that greenhouse-gas emissions from agriculture in 2050 should be limited to no more than their 2005 levels. This acceptance recognises that this target would necessitate a reduction in the projected globally aggregated demand for animal products to an average (and more evenly shared) per-head intake of, at most, 90 g meat per day. Not more than 50 g of this should come from red meat from ruminant animals. Acceptability of this policy should be enhanced by the expected health gains, both for current high-consuming populations, as their consumption reduces, and for low-consuming populations, as their consumption increases to an agreed, globally shared, but modest, level. This proposal could well prove to be too conservative, but has been formulated with the aim of furthering debate in this largely overlooked area of climate-change mitigation policy.

Short term: 2015

High-income countries should develop incentive structures and educative measures to be introduced between now and 2015, to initiate substantial contractions in the effects of the production and consumption of animal products on climate change. All countries should provide incentives for research and development for technologies to reduce greenhouse-gas emissions per unit of food product, plus incentives to fully deploy available mitigation technologies.

Medium term: 2030

Countries that were already above target in 2005 should be half-way from 2005 baseline to the target of 90 g per day per person. In countries in which consumption in 2005 was rising rapidly, increases in consumption should have slowed or halted, converging towards the target level. Countries with low consumption in 2005 should be increasing levels of consumption towards the target. All countries should have in place incentive structures to induce widespread adoption of mitigation techniques, together with research and development towards greater mitigation at acceptable cost.

Long term: 2050

All countries should have met the minimum acceptable emissions target. This target should have been achieved mainly by constraining emissions from livestock production. Restricting the intake of red meat from ruminant animals to 50 g per person per day, along with technical advances in livestock production, could reduce total livestock-related emissions below the 2005 level.

greenhouse-gas emissions, and protecting the food supplies, wellbeing, and health of vulnerable populations from being harmed by climate change. Enlightened policy responses would both benefit health and enhance sustainability.

The human quest for food: the long historical view

Life processes depend on the cyclical use of carbon, oxygen, water, and energy. Throughout nature the relations between energy, food, and health are fundamental: (1) plants use solar energy to synthesise organic matter, which, together with trace elements, becomes the base of the food web for the animal world; and (2) both plants and animals must use energy and nutrients to grow, feed, and reproduce. The evolution of human culture through three main historical phases has added complexity to these basic relations.

Hunter-gatherers

Hunter-gatherers expended somatic energy to gather and catch wild foods. Many hunter-gatherer societies seem to have obtained sufficient food without excessive exertion, typically assisted by low population density and territorial vigilance. Some hunter-gatherer communities had specialists—eg, Australian aboriginal tool makers.¹

In nature, each local population of a species is limited in size mainly by food supplies—ie, energy expenditure cannot sustainably exceed energy availability. That delimited population size equates to the local environment's carrying capacity for that species (a parameter that is more nuanced for human beings, being modifiable by trade and environmental intervention). In many temperate-zone environments, 100 hectares can typically carry 50–100 hunter-gatherers; an indication of the sustainable food yield. The energy density of most wild foods is low (exceptions being occasional caches of honey, high-fat organs, and in-season fat deposits in animals).

Agrarian communities

Agrarians worked harder and produced more food; their way of life could support a greater population density than could that of hunter-gatherers or nomadic herders. Human somatic energy has been progressively supplemented by that of beasts-of-burden. Later, water and wind power were also introduced, supplemented by purposeful use of gravity—eg, hillside terracing and water flows between paddy fields.

As for hunter-gatherers, the per-family energy expenditure in simple agrarian communities could not exceed food energy intake. However, as societies urbanise, differentiate, and stratify, and as trade develops, higher inputs of energy (including from exploited slaves and serfs) yield surplus food for consumption by urban dwellers or for sale by trade.

Early farming first emerged in widely dispersed locations around the world, from around 10–11 millennia ago. Although this emergence provided food for larger populations, there was an apparent cost to health through malnutrition²—eg, reduced skeletal stature with impaired growth of teeth and long bones.^{3,4} Infectious diseases increased because of larger and denser settled populations

and greater exposure to zoonoses acquired from domesticated animals and proliferating pests. In many agrarian populations, chronic energy deficiency associated with small body size would have reduced work capacity⁵ (and impaired brain development and learning ability), thereby exacerbating the recurrent subsistence crises that often caused starvation and increased mortality.

Although many pre-agricultural societies enjoyed abundant food on a year-round basis,¹ for millennia many human populations (especially farming populations) seem to have endured periodic food scarcity, especially early in the growing season when stored foods either spoil or are exhausted. Against these survival pressures, evolutionary forces favoured the development of various genetic characteristics—eg, lactose tolerance and gluten tolerance, which both vary in prevalence between regional populations in proportion to the time since their forebears first encountered milk and wheat foods³—and culturally shared behaviours that increased energy intake and storage to a maximum.

Second agricultural revolution (high-income countries)

The second, ongoing, agricultural revolution has entailed worldwide changes in capacity and productivity over the past three centuries. Such changes include the intercontinental exchange of cultivars (eg, the eventual adoption as a dietary staple, in Europe, of potatoes introduced from South America), privatisation of once-shared common land, fertiliser synthesis, powered mechanical farm equipment, the so-called green revolution (ie, intensive use, during the 1970s and 1980s, in many developing countries, of irrigation and fertiliser in conjunction with new high-yielding strains of cereal grains), the advent of genetic engineering, and today's more intensive landless livestock farming with globalised animal-feed sources. These developments have enabled food supply to keep pace with—perhaps even allow—world population growth. The current world food system provides 85% of the world's population with an adequate or, for some, excessive supply of protein and energy, although only two-thirds of the world's population is replete with essential micronutrients.⁶

This second agricultural revolution became increasingly dependent on non-renewable energy inputs, mainly from fossil fuels. Oil was used also to produce nitrogenous fertilisers. These huge new energy inputs have caused two radical changes in the age-old energy balance between food acquisition and consumption. First, post-industrial societies have acquired a systematic imbalance in the energy budget of daily living, with the net energy gain stored as body fat and manifesting as the present obesity pandemic. Second, in some countries, total energy input into food production now greatly exceeds food energy yield; without future new and environment-compatible energy sources, this is not sustainable.

The bonanza of cheap, non-renewable energy has contributed to the extraordinary modern surge in human numbers. Quasi-exponential increases in per-head energy consumption and human population numbers, complemented by rising levels of wealth and consumer expectation, are now pressing increasingly on the world's food-producing systems. Eventually, the human carrying capacity of that environmental base is liable to be exceeded.⁷⁻⁹ Indeed, several recent international assessments^{10,11} conclude that the total human demand for energy, material, and waste disposal now clearly exceeds the biosphere's capacity to supply, cleanse, replenish, and absorb. However, before looking to future prospects we will briefly review the health consequences of the new era of dietary abundance as societies modernise and wealth accrues.

Health gains and losses from dietary abundance

Fogel² attributes the remarkable gains in life expectancy in modern western populations largely to their expanding food supplies. First, subsistence crises diminished and disappeared; cycles of bad weather, poor crops, dearer food, hunger, and death ceased. Then, after the public-health setbacks associated with urbanisation in the early 19th century, a general marked decline in mortality emerged. By the late 20th century, adult men in countries such as England, Norway, and Sweden were around 10 cm taller and 20–30 kg heavier than were their predecessors two centuries earlier. The transformation in childhood growth and attained adult size indicated increased food supplies and less infection. This transformation of early-life nutrition and bodily growth has apparently underpinned these unprecedented health levels, most evident in today's high-income countries.

Access to adequate food—in terms of quantity and quality—has not yet become universal, however, and an estimated 850 million people remain energy-undernourished.¹² Nor is food energy abundance—especially in the form of refined and selectively produced energy-dense (high fat, high sugar) foods—intrinsically good for health.

A widespread tendency in recent decades, especially in higher-income populations, has been for death rates from non-communicable diseases at middle and older ages to fall, in parallel with deaths from communicable causes.¹³ Since around 1970, many high-income countries have enjoyed marked decreases in adult mortality rates from chronic diseases, especially from peaks in premature mortality from ischaemic heart disease. An important exception to this favourable pattern has been the surge since the 1960s in male cardiovascular deaths in Russia and other ex-Soviet states,¹⁴ to which the change in dietary patterns was just one of several apparent contributors.

There are, however, two reasons for concern about adult health prospects as incomes rise in low-income and middle-income countries and as they undergo

demographic, nutritional, and epidemiological transitions. First, attaining favourable adult health levels will very probably require concerted effort along a path analogous to that followed by today's high-income countries. Second, the quest for improved adult health must, today, contend with the emerging global trend towards energy imbalance, and hence being overweight and obese, while seeking to eliminate the socioeconomically related deficits in linear bodily growth (stunting) of young children that impair mental development and adult economic productivity and increase the risk of chronic disease.

The nutrition transition and health

Dietary and nutritional patterns have changed widely around the world in recent decades. Actual patterns of change, at the country level, have varied considerably, as has the mix of health gains and losses.

Beyond the health gains from food abundance, increases in national wealth and urbanised living potentiate consumption of refined, processed, and energy-dense foods in place of grains, legumes, and other sources of fibre. In recent decades, marked increases in the consumption of foods high in fats and sugars and decreases in physical activity have been widespread, especially in sedentary urban populations.¹⁵

In low-income and middle-income countries, strong trends are evident for increases in the proportion of calories derived from fat. In most countries with meaningful survey data (ie, mostly higher-income countries within this group), dietary fat now accounts for 26–30% of caloric intake. The proportion of calories from total protein has not changed, remaining at around 12% of total (which accords with protein sufficiency). However, there has been a marked increase in the availability of animal protein, especially poultry, and the consumption of red meats continues to rise, especially in China and Brazil. Per-head consumption of vegetable oils has increased several fold in many countries, as has consumption of refined sugar.

This unhealthy component of the nutrition transition has contributed much to a widespread rise of obesity and related chronic diseases (including metabolic and vascular diseases, in particular, type 2 diabetes and ischaemic heart disease and, less certainly, some cancers). Hence, some affected countries now face the double burden¹⁶ of under-nutrition due to nutritional deficits in parts of their populations and an increase in obesity-related chronic diseases due to increased availability of foods of animal origin, high in saturated fat, and energy-dense processed foods rich in fats and sugar.¹⁷ Meanwhile, many low-income countries already have age-specific risks of death from all chronic diseases combined that exceed those in high-income countries.¹⁸

Economic development and associated urbanism could lead to diets that are less protective against chronic diseases than are traditional diets. A particular example

is that of the former Soviet Union, with its consumer subsidies for animal foods and associated rise in vascular disease. In many countries, the traditional rural diet is based largely on vegetable products with small quantities of animal foods, and thus differs from the typical higher-income urban diet in the type and amount of fat content, the virtual absence of simple sugars (except honey or fruit), and the higher fibre content. Such differences have been well documented in India,¹⁹ where rates of diabetes, hypertension, and coronary heart disease were found to be consistently and clearly less in rural than in urban populations, and in Mexico, Brazil, and Chile.²⁰ The association between dietary and other associated modernisation and the overall risk of chronic diseases, however, is not straightforward. In China, for example, adult mortality remains higher in rural areas than in urban areas because the rates of many chronic diseases unrelated to dietary affluence remain high there.

Income, food prices, choices, and health

Data from the Food and Agriculture Organisation (FAO) from different countries and regions indicate that higher incomes are associated with greater access to food energy, higher consumption of animal products (meat and dairy), and reduced consumption of grains and complex carbohydrates (including in fruits and vegetables). Consumption of sugars, total fat, and animal fat also rises with income, leading to more energy-dense diets. Usually, these changes occur unevenly within a population. Diverse survey data show that, as transition proceeds, higher-income households typically spend more on food eaten away from home, especially meat and other animal products, and less on grains and oil. Poorer households, by contrast, typically have less varied diets, often exceeding energy needs, while being deficient in vitamins and minerals. Further intra-population differentials evolve with time.

The usual expectation is that the prices of high-demand foods will rise while those with low demand will fall. Such a scenario is often true for seasonal fruits, which are expensive early in the season, but cheaper later. However, recent trends for energy-dense foods such as vegetable oils and high-sugar soft drinks show a trend in the opposite direction: as demand rises, their prices drop because of economies of scale achieved by the greater volume of production.²¹

In the fast-food trade, higher consumption optimises production systems and thus lowers the unit price, allowing a larger (so-called super sized) serving. The addition of salt, sugar, and colouring further enhances consumption of energy-dense fatty foods. Our palaeolithically conditioned biological and behavioural regulation of appetite is not attuned to resisting this temptation. Nationally representative data for the USA indicate that at least 40% of the increase in the prevalence of obesity over the past 25 years is reasonably attributable

to the reduced unit price of food, especially foods high in fat and sugar.²²

Climate change: prospects for food yields

The basic science of human-induced climate change has been well documented.²³ Although the main human source of greenhouse-gas emissions is combustion of fossil fuels for energy generation, non-energy emissions (including from agriculture and land-use changes) contribute more than a third of the total greenhouse-gas emissions worldwide.²³ Climate change is doubly relevant here: first, climate change will affect food yields and therefore health; second, food production itself contributes substantially to climate change and hence to its diverse effects on health.

Assessments of the effects of climate change (entailing changes in temperature, rainfall, humidity, and extreme weather events) on the quantity and security of food supplies requires complex modelling, spatially differentiated across Earth's productive land surface. In the 1990s, first-order models forecast that climate change would result in agricultural winners and losers, in rough balance, but with developing countries being more vulnerable.²⁴ Later versions of these studies indicate that this inequality will probably worsen.^{25,26} The IPCC's Fourth Assessment Report²⁷ concludes that, by 2020, crop yields could increase by 20% in east and southeast Asia, but decrease by up to 30% in central and south Asia, and that rain-fed agricultural output could drop by 50% in some African countries.

In related research, Fischer and colleagues²⁵ initially modelled projections to 2080, assuming no climate

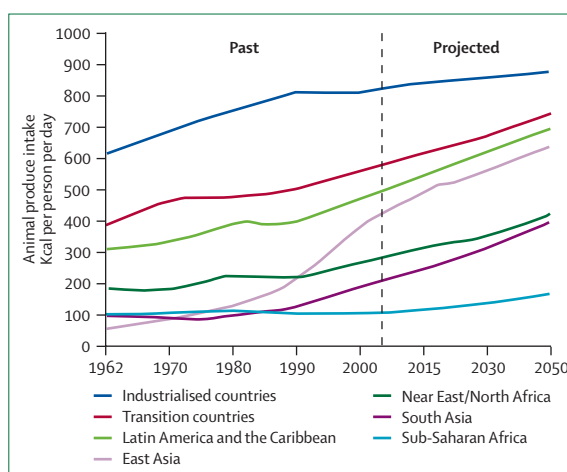


Figure 1: Trends in consumption of livestock products per person (milk, eggs, and dairy products, excluding butter)

The projected trends assume no policy-induced change from present consumption. Note the rapid recent increase in east Asia, dominated by China, where per-head meat consumption would reach European levels by mid-century. Cultural, agricultural, and political factors will determine how the composition of animal products intake actually changes in the future. For example, in the near east and in north Africa, higher intake of milk, eggs, and poultry are likely, whereas greater consumption of beef and poultry is expected to dominate the increase in Latin America.⁴³ Reproduced from FAO,⁴² with permission.

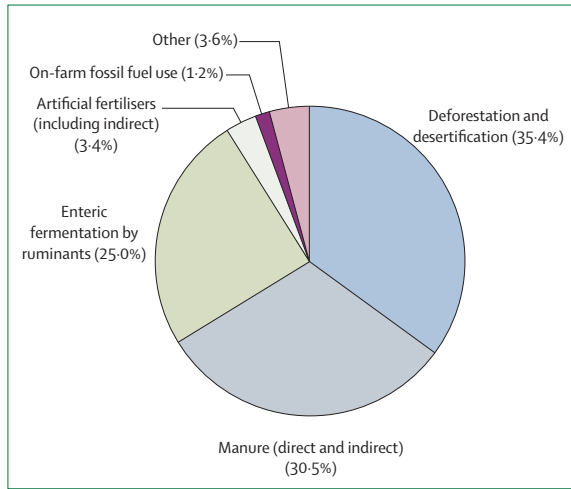


Figure 2: Proportion of greenhouse-gas emissions from different parts of livestock production
Adapted from FAO.⁴²

change. On all but the most pessimistic development scenario, the number of under-fed individuals more than halves, from around 850 million today to less than 300 million in 2080. When climate change projections are added (and assuming a beneficial carbon fertilisation effect), the projected global production of food-grain does not change substantially, but regional divergence increases. Yields fall at low latitudes and increase at high latitudes. Low-income countries, reflecting geographic and climatic zones, are projected to lose 5–10% of overall cereal production. Furthermore, under all but one climate scenario, this loss varies geographically, with 1–3 billion people in poor and food-insecure countries facing estimated losses of 10–20% of cereal production under climate change.²⁵

The FAO has been slow to address the issue of climate change and agriculture: a 2003 report from the organisation acknowledged climate change as a serious future problem, with little or even positive near-term effects.²⁸ Meanwhile, many other recent articles and reports indicate, collectively, that the adverse effects of

	Daily meat consumption per person (g)
Africa	31
East and south Asia	112
West Asia (including Middle East)	54
Latin America	147
Developing countries (overall)	47
Developed countries (overall)	224
Total	101

Quantities actually ingested will be lower, especially in high-income countries, where the proportion wasted is higher. 80–100 g of meat is roughly equivalent to a beef patty in a regular hamburger. An American quarter-pounder is about 115 g of meat.

Table 1: Daily meat consumption, by region³³

climate change on global agriculture could have been underestimated. In particular, the posited carbon fertilisation effect, whereby increased atmospheric levels of carbon dioxide benefits crop growth, might have been overestimated.²⁹ This assumed effect was integral to the earlier, comparatively benign, model forecasts, which also assumed, probably optimistically, that the quality of higher latitude soils would allow farmers to exploit the longer growing season predicted under climate change.³⁰

Other recent studies have raised further doubts about earlier modelled estimates. Recent research shows reductions in rice yields from hotter nights,³¹ complementing a finding that global yields of wheat, maize, and barley are impaired by higher temperatures.³² Increased drought severity due to climate change has also been forecast,³³ as has a marked shrinking of glaciers in the Himalayas and Andes, which is likely to decrease summer irrigation in some of Asia's and South America's most fertile and densely populated river basins.³⁴ The potentially damaging effects of increases in the frequency of extreme weather events, pest infestations, diseases, and, for coastal and island populations, sea-level rise, have not yet been incorporated in these models.

The Stern report³⁵ underscores recent serious concerns for future food security, especially in sub-Saharan Africa.²⁶ Populations in low-income countries are at greatest risk, being more sensitive to exacerbation of food insecurity, reliant on local food production, and having lesser adaptive capacity. But high-income countries also face problems—eg, Stern³⁵ forecasts diminished agricultural productivity in southern Australia.

Global climate change: health risks

The health risks from climate change are the topic of increasing research attention and policy development.^{36,37} Health risks result from physical hazards, temperature extremes, effects on air quality, altered patterns of transmission of infectious diseases, and effects on food

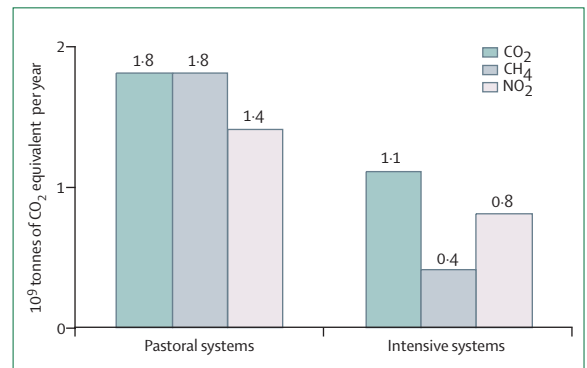


Figure 3: Contribution of extensive (pastoral) and intensive (feed-supplemented, including feed-lot) livestock systems to greenhouse gas emissions
Adapted from FAO,⁴² with permission.

yields. Population displacement and conflict are also likely, because of various factors including food insecurity, desertification, sea-level rise, and increased extreme weather events.³⁸ The rising prospects for biofuels as a renewable energy source for transport add further technical and moral complexity to the relations between energy, food, and health.³⁹ The potential for competition between these uses of land are discussed in this Series by Haines and colleagues.⁴⁰

Agriculture, land use, and greenhouse-gas emissions: producing both meat and heat?

Worldwide, greenhouse-gas emissions from agriculture (crop production and animal husbandry) and associated changes in land use, are estimated to exceed those from power generation and transport. Methane and nitrous oxide, combined, are more important emissions from this sector than is carbon dioxide. Methane is a potent greenhouse gas whose full contribution to climate change has recently been re-assessed as being more than half that of carbon dioxide.⁴¹

A recent FAO report⁴² focuses specifically on the current and future effects of livestock production on the world's environment and climate. The report states that the world's livestock sector, which provides the livelihoods of about 1.3 billion people, is growing faster than other agricultural subsectors. Yearly worldwide meat production is projected (in the absence of policy induced changes of trend) to double from 229 million tonnes in 1999–2001 to 465 million tonnes in 2050, and milk output to almost double from 580 million tonnes to 1043 million tonnes. Most of this increase is projected to occur in countries with low or middle incomes (figure 1). Livestock currently use almost a third of the world's entire land surface, mostly permanent pasture, but also including the third of the world's arable land that provides livestock feed.

Much of the estimated 35% of global greenhouse-gas emissions deriving from agriculture and land use³⁵ comes from livestock production. Livestock production—including deforestation for grazing land and soy-feed production, soil carbon loss in grazing lands, the energy used in growing feed-grains and in processing and transporting grains and meat, nitrous oxide releases from the use of nitrogenous fertilisers, and gases from animal manure (especially methane) and enteric fermentation⁴⁴—accounts for about 18% of global greenhouse-gas emissions (figure 2).⁴² This estimate consists of around 9% of global emissions of carbon dioxide, plus 35–40% of methane emissions and 65% of nitrous oxide, both of which have much greater near-term warming potential over several ensuing decades than does carbon dioxide (although they have shorter half-lives in the atmosphere). Similar estimates exist of the contributions of UK farming, live-stock production, and the food chain overall, to national greenhouse-gas emissions.⁴⁵

The FAO report extends Lappé's well known "diet for a small planet" argument⁴⁶ that feeding a population on

	Carbon dioxide (global, 2002)	Methane, enteric (global, 2004)	Methane, manure (global, 2004)
Cattle	1906	75*†	8‡
Small ruminants (sheep and goats)	514	9	0.3
Pigs	590	1	8
Camels	18
Horses	71
Poultry	61	..	1
Total	3161	86	18

Data are million tonnes of gas. *Dairy cattle account for a quarter of enteric methane emissions from cattle. †Buffaloes contribute 9 million tonnes. ‡Buffaloes contribute 0.3 million tonnes.

Table 2: Greenhouse-gas emissions per year from livestock⁴²

a diet of animal protein requires an order of magnitude more farmland than does a diet of plant protein. Today, as Chinese, other Asian, European, and US farmers begin to run short of land for crop expansion, the increasing demand for meat in developing economies is forcibly extending intensive agriculture into the tropical rainforests of South America, especially Brazil, Bolivia, and Paraguay.⁴⁷

Current levels of meat consumption, by region, are shown in table 1. China's meat consumption has doubled over the past decade.⁴³ A net soybean exporter until 1993, China has relied increasingly on Brazilian soybean protein to feed its expanding populations of chickens and pigs. India, South Africa, and some other emerging economies are now also beginning to import soybeans. Meanwhile, during that same decade, to offset the animal-feed protein shortfall caused by the BSE-triggered banning of offal, the European Union's annual imports of soy soared from 3 to 11 million tonnes.

Whether conventional and organic systems of animal husbandry differ materially in terms of energy use and emissions of greenhouse gas per unit production is contentious; studies have produced inconsistent results. A recent UK analysis concludes that, although organic production uses less total energy per kilogram of meat output than conventional production, it emits more greenhouse gases.⁴⁸ Feeding animals higher-quality digestible feed-grain concentrates reduces methane emissions from enteric fermentation (and achieves more efficient conversion of actual food energy). The FAO report shows that, in absolute terms, the total greenhouse-gas emissions from intensive (feed-grain based) production methods—especially methane—are much less than from extensive (pasture-based) methods (figure 3).⁴² That difference, however, also reflects the predominant reliance on extensive methods, worldwide. The global contributions of the major categories of livestock to greenhouse-gas emissions are shown in table 2.

The case for restricting production and consumption of red meat

Given the projected increases in global livestock production and in associated greenhouse-gas emissions if policies do not change, urgent attention needs to be paid to finding ways of reducing the demand for animal products and the energy intensity of their production.

As has been proposed for greenhouse-gas emissions at large, emphasising international equity, a contraction and convergence policy⁴⁹ seems to be the most defensible—and therefore the most politically feasible—model for restricting emissions arising in relation to consumption of meat and dairy products. Because rapid reductions in greenhouse-gas emissions per unit of livestock production would be technically and culturally difficult in the short term, the prime objective must be to reduce consumption of animal products in high-income countries, and thus lower the ceiling consumption level to which low-income and middle-income countries would then converge.

The main options for reducing greenhouse-gas emissions per unit of animal production include: (1) sequestering carbon and mitigating carbon dioxide emissions by reduction and reversal of deforestation arising from agricultural intensification and by restoration of organic carbon to cultivated soils and degraded pastures; (2) reducing methane emissions from enteric fermentation (especially in ruminants such as cattle, sheep, and goats) through improved efficiency and diets; (3) increasing the proportion of chickens, monogastric mammals, and vegetarian fish in the flow of animals grown for human consumption; (4) mitigating emissions of methane through improved management of manure and biogas; and (5) mitigating emissions of nitrous oxide via more efficient use of nitrogenous fertilisers.

Recent reviews suggest that available mitigation technologies could reduce emissions per unit of animal

product by up to 20% at fairly low costs. However, reductions beyond that level are not currently available at realistic prices.⁵⁰

In view of the need to reduce consumption of animal products to help avert climate change, the likely health effects of any such reduction must be considered, especially any potential for harm. No substantial health risks are apparent from reduction of mean meat consumption to the levels proposed here (although iron deficiency in menstruating women and high-intensity athletes might warrant caution). Indeed, important gains to health are likely from reduced intakes in populations that currently consume above the proposed target.

A reduction in colorectal cancer risk would be very likely.⁵¹ The absolute magnitude of this reduction is somewhat uncertain because of the difficulty in quantifying the usual absolute meat intake of individuals in epidemiological studies. One study has estimated that the risk of colorectal cancer decreases by about a third for every 100 g per day reduction in consumption of red and processed meat.^{52,53} In high-income countries, where the average adult's daily total meat consumption is about 200–250 g, the average cumulative risk of death from colorectal cancer before age 70 years is about 1%, so the absolute reduction in the risk of premature death would be modest. Reduced consumption of red meat could also lower the risk of other cancers, including breast cancer.^{54,55}

More uncertain is the extent to which the risk of ischaemic heart disease would be reduced. Many fewer studies have reported on associations between meat intake and the risk of ischaemic heart disease than between food constituents (especially fats) and risk. Further, any causal role for meat consumption in ischaemic heart disease is assumed to be largely mediated by its fat content, which is potentially modifiable. Hu and Willett⁵⁶ concluded from their review of the evidence that: “Diets containing substantial amounts of red meat and products made from these meats probably increase risk of coronary disease”. Since, in high-income countries, risks of premature death from heart attack are several times higher than for colorectal cancer, this association, even if more uncertain, is of potentially greater public-health importance.

Strategies to reduce consumption of animal foods might foster vegetarianism. Therefore, the healthiness of vegetarian diets is also relevant. A recent review⁵⁷ concluded that “cohort studies of vegetarians have shown a moderate reduction in mortality from [ischaemic heart disease] but little difference from other major causes of death or all-cause mortality in comparison with health-conscious non-vegetarians from the same population”.

Contraction from high consumption levels in high-income countries will make space for increases in low-income countries from their current low levels of consumption of animal products. For adults, the strongest

	High-income countries	Low-income countries
Current approximate total meat consumption (g per day per person)	200–250	25–50
Change in		
Heart disease*	---	+
Stroke	No substantial effect	---
Colorectal cancer	---	++
Breast cancer	--†	+
Childhood growth stunting	No substantial effect	----
Overweight/obesity	--	(+)

Risk shifts refer only to the effect of a change in meat consumption. Other associated dietary changes are not considered. *Attributable mainly to saturated fat content. †Less certain than for bowel cancer.

Table 3: Direction and likely extent of change in risk of health outcomes in response to future achievement (proposed for 2050) of a proposed international target of 90 g per day per person in all countries

evidence for a protective role from modest, rather than low, intakes of animal products is for stroke.⁵⁸⁻⁶¹ This finding was consistent in studies of Japanese populations, where the rising consumption of animal products has been credited with contributing to the reduction in stroke mortality. Detailed ecological studies across 69 rural counties in China in the 1980s found that mortality from all causes, and especially from stroke, was lowest in counties where consumption of animal products was highest.⁶²

In framing policy, a reasonable conclusion is that substantial contractions in consumption of animal products from current levels in high-income countries, combined with increased levels in populations where consumption is very low, is unlikely to harm health and should bring substantial health benefits (table 3).

An additional health benefit from a reduction in livestock production—by reducing both land clearance (used for feed production or for grazing) and curtailing intensive livestock production—would be to decrease human contact with new infectious agents. Recently, such environmental incursions and commercial practices have facilitated the emergence of zoonotic infections, including various viral haemorrhagic fevers, avian influenza, Nipah virus from pig farming, and BSE in cows and its human variant.^{63,64} Other health benefits would also result from curtailment of the environmental degradation associated with livestock production: the alienation of freshwater supplies, nitrification of soil and water, and dissemination of other zoonotic pathogens (eg, cryptosporidium, hydatid, etc). Recognition of this wider constellation of health effects in relation to societies' choices of types of foods and production methods underlies the integrative new nutrition science approach to policy decisions about food, nutrition, environment, and health.⁶⁵

An important issue of international equity also arises. Although developing countries now account for about two-fifths of global emissions of carbon dioxide, they produce more than half of nitrous oxide and nearly two-thirds of methane emissions. The largest share of livestock-related greenhouse-gas emissions comes from pastoral production systems, with which many rural livestock holders, operating on a small scale, eke out livelihoods from limited natural resources.⁶⁶ Such individuals currently lack the money to upgrade production methods to lower-emission standards. Yet, since most of the huge projected increase in global meat production and consumption is expected to occur in developing countries, the more greenhouse gas-intensive traditional rural production methods will come under increasing competitive commercial and regulatory pressure, even though their methods entail fewer distortions or violations of natural processes. Equitable resolution will require enlightened national government policies, international trade, and other agreements.

Conclusions

For human beings, historically, as for the animal world at large, the fundamental point about food and energy has been that, to survive, an individual must acquire at least as much food energy as is expended in basal metabolism, reproducing, and acquiring food. In recent times, the focal point of the interaction between food, energy, and health has shifted radically. Access to unprecedented levels of useable energy, and intensified agricultural (especially livestock production) practices, accounts for most of the human-generated greenhouse-gas emissions that are causing climate change. That change, in turn, poses great risks to population health, including by affecting food yields and nutrition.

To avert dangerous climate change, the primary need is for radical change in energy generation technologies and energy use. However, since human-induced climate change is now occurring (and with more change already committed), we believe that two additional policies are necessary: (1) to help populations at risk of adverse health effects from climate change to minimise those risks; and (2) to minimise total greenhouse-gas emissions from livestock production, which would include change in land use.

A universal policy of demand reduction for all animal products in all countries, irrespective of current levels, would be politically infeasible, not least because of its obvious inequity. Not surprisingly, then, many key policy documents seem to have sidestepped this issue (by contrast with the readier use of demand management in areas such as energy policy). Reductions in the intensity of production of greenhouse gases and of animal products, and in consumer demand are needed. An effective contraction and convergence policy would therefore seek to: (1) reduce greenhouse-gas emissions per unit of meat or milk produced; (2) reduce consumption of meat (especially ruminant red meat) and milk from the current high levels in high-income countries, with predicted health benefits; and (3) taper the rise in consumption of meat and milk in developing countries, also with predicted health benefits.

Against the argument that contraction and convergence would not work because of strong consumer preferences for meat we argue that the unprecedented serious challenge posed by climate change necessitates radical responses. Although the prime need is to transform energy generation and use, the urgent task of curtailing global greenhouse-gas emissions necessitates action on all major fronts. For the world's higher-income populations, greenhouse-gas emissions from meat-eating warrant the same scrutiny as do those from driving and flying, especially in view of the great warming potential of methane in the short-to-medium term. As this situation becomes better recognised, an emerging political consensus would hopefully support such measures. Privileged groups in high-income countries (including the UK⁶⁷) have already shown willingness to reduce their consumption of animal foods, apparently in relation to the risk of cardiovascular disease.

Removing state subsidies for animal feed (corn and soy) would, via increases in retail prices, help to reduce meat consumption and redirect grain harvests to local low-income country diets. Stern, noting first the difficulty of measuring and pricing actual livestock emissions, and, second, the world's many small-farm emitters (especially in lower-income countries), recommends carbon-pricing of greenhouse-gas proxies such as livestock feeds.³⁵ This method needs refinement to be more inclusive, and to deal with differing emissions intensity between different livestock production methods.

Meanwhile, total consumption of animal foods would, of course, be reduced by further slowing of world population growth, which could be achieved, without coercion, by education, leadership, and wider availability of contraceptive knowledge and methods. Slower population growth would help to achieve the Millennium Development Goals⁶⁸ and constrain climate change.

Some national governments have resisted international measures to reduce greenhouse-gas emissions on the grounds that they would impede economic growth. However, as Stern concludes, strong and prompt measures to reduce greenhouse-gas emissions are necessary to preserve long-term prospects for enhancing economic development.³⁵ Hence the measures to reduce emissions proposed here are actually pro-growth in at least the longer term.

Many collateral health gains should accrue from these proposed changes, undertaken to stabilise world climate and secure our future, including a healthier diet, improved air quality, more reliable freshwater supplies, and reduced tensions in a more environmentally attuned world. On a worldwide level, the achievement of rational energy use, food production, and associated environmental sustainability would underpin wellbeing, health, and longevity for human populations and the world's environment.

Conflict of interest statement

We declare that we have no conflict of interest.

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References

- Sahlins MD. Stone age economics. Chicago: University of Chicago Press, 1972.
- Fogel RW. The escape from hunger and premature death, 1700–2100: Europe, American and the third world. Cambridge: Cambridge University Press, 2004.
- McMichael AJ. Human frontiers, environments and disease. Past patterns, uncertain futures. Cambridge: Cambridge University Press, 2001.
- Steckel R, Rose JC. The backbone of history. Health and nutrition in the western hemisphere. Cambridge: Cambridge University Press, 2002.
- Horton S. Opportunities for investments in nutrition in low-income Asia. In: Hunt J, Quibria MG, eds. Investing in child nutrition in Asia. Manila: Asian Development Bank, 1999.
- Black R. Micronutrient deficiency—an underlying cause of morbidity and mortality. *Bull World Health Organ* 2003; **81**: 79.
- Diamond J. Collapse: how societies choose to fail or succeed. London: Penguin Books, 2005.
- McMichael AJ. Planetary overload. Global environmental change and the health of the human species. Cambridge: Cambridge University Press, 1993.
- Tainter JA. The collapse of complex societies. Cambridge: Cambridge University Press, 1988.
- WWF. Living Planet Report 2006. Gland, Switzerland: World Wide Fund for Nature, 2006. http://assets.panda.org/downloads/living_planet_report.pdf (accessed Aug 28, 2007).
- Wackernagel M, Schulz NB, Deumling D, et al. Tracking the ecological overshoot of the human economy. *Proc Natl Acad Sci USA*, 2002; **99**: 9266–71.
- FAO. The state of food insecurity in the world 2005. Rome: Food and Agriculture Organisation, 2005: 36.
- Salomon JA, Murray CJL. The epidemiologic transition revisited: compositional models for causes of death by age and sex. *Popul Dev Rev* 2002; **28**: 205–28.
- Shkolnikov V, McKee M, Leon DA. Changes in life expectancy in Russia in the mid-1990s. *Lancet* 2001; **357**: 917–21.
- Joint WHO/FAO Expert Consultation. Diet, nutrition and the prevention of chronic diseases. *World Health Organ Tech Rep Ser* 2003; **916**: 1–149.
- Uauy R, Solomons NW. The role of the international community: forging a common agenda in tackling the double burden of malnutrition. News 32. Geneva, Switzerland: UN Standing Committee on Nutrition, 2006: 24–37. <http://www.unsystem.org/SCN/Publications/SCNNews/scnnews32.pdf> (accessed Aug 21, 2007).
- Anderson G, Chu E. Expanding priorities—confronting chronic disease in countries with low income. *N Engl J Med* 2007; **356**: 209–11.
- Ezzati M, Lopez AD, Rodgers A, Vander Hoorn S, Murray CJL. Selected major risk factors and global and regional burden of disease. *Lancet* 2002; **360**: 1347–60.
- Vaz M, Yusuf S, Bharathi A, Kurpad A, Swaminathan S. Notes: the nutrition transition in India. *S Afr J Clin Nutr* 2005; **18**: 198–201.
- Popkin BM. An overview on the nutrition transition and its health implications: the Bellagio meeting. *Public Health Nutr* 2002; **5**: 93–103.
- Drewnowski A, Darmon N. The economics of obesity: dietary energy density and energy cost. *Am J Clin Nutr* 2005; **82**: S265.
- Lakdawalla D, Philipson T. The growth of obesity and technological change: a theoretical and empirical examination. Working paper number 8946. Cambridge, MA: National Bureau of Economic Research, 2002.
- IPCC. The physical basis of climate change. Geneva, Switzerland: Intergovernmental Panel on Climate Change, 2007. <http://ipcc-wg1.ucar.edu/wg1/wg1-report.html> (accessed July 31, 2007).
- Rosenzweig C, Parry ML. Potential impact of climate change on world food supply. *Nature* 1994; **367**: 133–38.
- Fischer G, Shah M, Tubiello FN, van Velhuizen H. Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990–2080. *Philos Trans R Soc Lond B Biol Sci* 2005; **360**: 2067–83.
- Parry ML, Rosenzweig C, Iglesias A, Livermore M, Fischer G. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Glob Env Change* 2004; **14**: 53–67.
- Intergovernmental Panel on Climate Change. Climate change 2007: impacts, adaptation and vulnerability. Report of Working Group II. Geneva: World Meteorological Organisation, 2007.
- Bruinsma J, ed. World agriculture towards 2015/2030. An FAO perspective. London: Earthscan, 2003.
- Long SP, Ainsworth EA, Leakey AD, Nosberger J, Ort DR. Food for thought: lower-than-expected crop yield stimulation with rising CO₂ concentrations. *Science* 2006; **312**: 1918–21.
- Fischer G, van Velhuizen H, Medow S, Nachtergaele F. Global agro-ecological assessment for agriculture in the 21st century. Laxenburg, Austria: IIASA, 2002.
- Peng S, Huang J, Sheehy JE, et al. Rice yields decline with higher night temperature from global warming. *Proc Natl Acad Sci USA* 2004; **101**: 9971–75.
- Lobell DB, Field CB. Global scale climate-crop yield relationships and the impacts of recent warming. *Environ Res Lett* 2007. Published online March 16. DOI.org/10.1088/1748-9326/2/1/014002.

- 33 Burke EJ, Brown SJ, Christidis N. Modeling the recent evolution of global drought and projections for the twenty-first century with the Hadley Centre climate model. *J Hydrometeorology* 2006; **7**: 1113–25.
- 34 Barnett TP, Adam JC, Lettenmaier DP. Potential impacts of a warming climate on water availability in snow-dominated regions. *Nature* 2005; **438**: 303.
- 35 Stern N. The economics of climate change: the Stern review. Cambridge: Cambridge University Press, 2006.
- 36 Haines A, Kovats RS, Campbell-Lendrum D, Corvalan C. Climate change and human health: impacts, vulnerability, and mitigation. *Lancet* 2006; **367**: 2101–09.
- 37 McMichael AJ. Climate change and human health: present and future risks. *Lancet* 2006; **367**: 859–69.
- 38 Butler C, Oluoch-Kosura W. Linking future ecosystem services and future human well-being. *Ecol Soc* 2006; **11**: 30.
- 39 Somerville C. The billion-ton biofuels vision. *Science* 2006; **312**: 1277.
- 40 Haines A, Smith KR, Anderson D, et al. Policies for accelerating access to clean energy, improving health, advancing development, and mitigating climate change. *Lancet* 2007; published online Sept 13. DOI:10.1016/S0140-6736(07)61254-9.
- 41 Shine KP, Sturges WT. Atmospheric science. CO₂ is not the only gas. *Science* 2007; **315**: 1804–05.
- 42 FAO. Livestock's long shadow. Environmental issues and options. Rome: Food and Agriculture Organisation, 2006: 414.
- 43 Schmidhuber J. Long-term changes in food consumption in patterns: concerns and policy options. Rome, Italy: FAO Scientific Workshop on Globalization of the Food System, 2004: 81–97. <http://www.fao.org/es/ESD/Schmidhuberdiets.pdf> (accessed July 29, 2007).
- 44 US EPA. Global anthropogenic non-CO₂ greenhouse gas emissions: 1990–2020. Washington DC: US Environmental Protection Agency, Office of Atmospheric Programs, 2006.
- 45 Baggott L, Brown L, Rand M, Murrells TP. UK greenhouse gas inventory, 1990 to 2003: annual report for submission under the Framework Convention on Climate Change. Harwell: AEA Technology, 2005.
- 46 Lappé FM. Diet for a small planet. New York: Ballantine, 1971.
- 47 Naylor R, Steinfeld H, Falcon W, et al. Agriculture. Losing the links between livestock and land. *Science* 2005; **310**: 1621–22.
- 48 DEFRA. Greenhouse gas emissions and the livestock sector. http://www.brass.cf.ac.uk/uploads/271005_TGpres.pdf (accessed Aug 13, 2007).
- 49 Meyer A. Contraction and convergence. The global solution to climate change. Foxhole, Devon, UK: Green Books for the Schumaker Society, 2000.
- 50 DeAngelo B, De la Chesnaye FC, Beach RH, Sommer A, Murray B. Methane and nitrous oxide mitigation in agriculture. *The Energy Journal* 2006; **89**–108.
- 51 WCRF. Food, nutrition, physical activity and the prevention of cancer: a global perspective. London, UK: World Cancer Research Fund. http://www.wcrf.org/research/second_wcrf_aicr_report.lasso (accessed Aug 18, 2007).
- 52 Norat T, Bingham S, Ferrari P, et al. Meat, fish, and colorectal cancer risk: the European prospective investigation into cancer and nutrition. *J Natl Cancer Inst* 2005; **97**: 906–16.
- 53 Norat T, Lukanova A, Ferrari P, Riboli E, et al. Meat consumption and colorectal cancer risk: dose-response meta-analysis of epidemiological studies. *Int J Cancer* 2002; **98**: 241–56.
- 54 Cho E, Chen WY, Hunter DJ, et al. Red meat intake and risk of breast cancer among premenopausal women. *Arch Intern Med* 2006; **166**: 2253–59.
- 55 Taylor EF, Burley VJ, Greenwood DC, Cade JE. Meat consumption and risk of breast cancer in the UK Women's Cohort Study. *Br J Cancer* 2007; **96**: 1139–46.
- 56 Hu FB, Willett WC. The relationship between consumption of animal products (beef, pork, poultry, eggs, fish and dairy products) and risk of chronic diseases: a critical review. Cambridge, MA: Harvard School of Public Health, 1998.
- 57 Key TJ, Appleby PN, Rosell MS. Health effects of vegetarian and vegan diets. *Proc Nutr Soc* 2006; **65**: 35–41.
- 58 Iso H, Stampfer MJ, Manson JE, et al. Prospective study of fat and protein intake and risk of intraparenchymal hemorrhage in women. *Circulation* 2001; **103**: 856–63.
- 59 Kinjo Y, Beral V, Akiba S, et al. Possible protective effect of milk, meat and fish for cerebrovascular disease mortality in Japan. *J Epidemiol* 1999; **9**: 268–74.
- 60 Reed DM. The paradox of high risk of stroke in populations with low risk of coronary heart disease. *Am J Epidemiol* 1990; **131**: 579–88.
- 61 Sauvaget CM, Nagano JM, Hayashi MB, Yamada MM. Animal protein, animal fat, and cholesterol intakes and risk of cerebral infarction mortality in the Adult Health Study. *Stroke* 2004; **35**: 1531–37.
- 62 Chen J, Peto R, Pan W, et al. Mortality, biochemistry, diet and lifestyle in rural China: geographic study of the characteristics of 69 counties in mainland China and 16 areas in Taiwan. Oxford: Oxford University Press, 2006.
- 63 Barnes E. Diseases and human evolution. Albuquerque: University of New Mexico Press, 2005.
- 64 Weiss RA, McMichael AJ. Social and environmental risk factors in the emergence of infectious diseases. *Nat Med* 2004; **10** (12 suppl): S70–76.
- 65 Leitzmann C, Cannon G. Dimensions, domains and principles of the new nutrition science. *Public Health Nutr* 2005; **8**: 787–94.
- 66 Delgado C, Rosegrant M, Steinfeld H, Ehui S, Courbois C. Livestock to 2020: the next food revolution. Washington: International Food Policy Research Institute; Food and Agriculture Organisation; International Livestock Research Institute, 1999.
- 67 Charlton J, Quaife K. Trends in diet 1841–1993. In: Charlton J, Murphy M, eds. The health of adult Britain 1841–1994. London: Government Statistical Service, 1997: 93–113.
- 68 Campbell M, Cleland J, Ezeh A, Prata N. Return of the population growth factor. *Science* 2007; **315**: 1501–02.