Meat consumption, health and the environment

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Summary

Background

The global average per capita consumption of meat and the total amount of meat consumed are rising (Figure), driven by increasing average individual incomes and by population growth. The consumption of different types of meat and meat products has significant effects on people's health, and livestock production can have major negative effects on the environment.

Advances

Meat is a good source of energy and some essential nutrients, including protein and micronutrients such as iron, zinc and vitamin B_{12}, though it is possible to obtain a sufficient intake of these nutrients without eating meat if a wide variety of other foods is available and consumed. In high-income Western countries, large prospective studies and meta-analyses generally show that total mortality rates are modestly higher in participants who have high intakes of red and processed meat. The strongest evidence of a specific adverse effect is the increased risk of colorectal cancer with high intakes of processed meat.

Meat produces more emissions per unit of energy compared with plant-based foods because energy is lost at each trophic level. Within types of meat, ruminant production usually leads to more emissions than non-ruminant mammals, and poultry less than mammals. Meat production is the single most important source of methane which has a relatively high warming potential, but a low half-life in the environment. Careful management of grassland systems can contribute to carbon storage but the net benefits are likely to be relatively modest. Agriculture uses more freshwater than any other human activity with nearly a third required for livestock, so meat production in water-stressed areas is a major competitor with other uses of water including in natural ecosystems. Meat production can be an important source of nitrogen, phosphorous and other

pollutants, and affects biodiversity in particular through land conversion to pasture and arable feed crops.

Outlook

Governments act to shape food systems for economic purposes and to protect health from contaminated food. But there is less agreement over the degree to which the state should use health, environmental or animal welfare considerations to control the supply of meat through interventions which affect the production, sale, processing and distribution of meat and meat products or the price to the consumer.

If we are to shape consumer demand, more evidence is needed about the effectiveness of different interventions to influence food selection. This may include interventions that impact on either the conscious, reflective decision-making systems or non-conscious, automatic processes. Potential interventions within the rational choice paradigm include labelling schemes (based on health or environmental criteria) and certification programmes (based on welfare or environmental considerations) or fiscal interventions. Alternatively, the largely automatic responses to environmental cues that affect purchase and consumption behaviours can be manipulated by changes to the food environment, in retail and food consumption settings.

History suggests that change in dietary behaviours in response to interventions is slow. But social norms can and do change and this process can be aided by the coordinated efforts of civil society, health organisations and government. However, it is likely to require a more complete understanding of the impact of meat consumption on health and the environment and a licence from society for a suite of interventions to stimulate change.

Figure legend

Figure 0. Total consumption of meat (in million tonnes) in different regions and (inset) globally; data from (*1*)

Abstract

Both the global average per capita consumption of meat and the total amount of meat consumed are rising, driven by increasing average individual incomes and by population growth. The consumption of different types of meat and meat products has significant effects on people's health, and livestock production can have major negative effects on the environment. Here we explore the evidence base for these assertions and the options policy makers have should they wish to intervene to affect population meat consumption. We highlight where more research is required and the great importance of integrating insights from the natural and social sciences.

Introduction

The amount of meat in human diets varies greatly among individuals within societies, and across different societies. At a global level, both the average per capita consumption of meat and the total amount of meat consumed are rising, driven by increasing average individual incomes and by population growth (*1*). More detailed analysis shows that there have been major changes in the type of meat we eat, in particular large increases in chicken and pork consumption (*1*). In addition, a greater fraction of the meat we eat today is processed before purchase (*1*).

Trends in the demand for meat matter for many reasons. Meat can be an important source of nutrients for people on low incomes with restricted diets but there is also evidence that high meat consumption may increase the risk for some types of chronic disease (*2*). Meat production is one of the most important ways in which humanity affects the environment: we cut down forests to create pasture as well as arable land to meet the demand for animal feed (*3*). Livestock production is a major source of greenhouse gases and other pollutants, in some areas makes major demands on scarce water resources (*4*), and can exacerbate soil erosion. But livestock also provide employment for large numbers of people and the trade in livestock and related food products is a core component of the economy of many countries (*5*).

Policy makers are increasingly grappling with the economic, health and environmental consequences of rising meat consumption. It is not clear the degree to which policy makers have the societal licence to intervene to influence meat consumption and, if they do, what interventions might be effective. These issues are particularly complex given the multiple narratives about eating meat that influence everyone's behaviour.

This article explores these intersecting drivers and attempts to place the natural science issues, such as the effects of meat consumption on health and the environment, in the context of the political economy and social factors that simultaneously determine individual behaviour and policy formulation.

Present and future meat consumption

Meat consumption at the population level can be estimated using self-reported dietary surveys which provide rich detail but are expensive to conduct (*6*). In practice, not all countries have access to this type of data, and therefore food balance sheets, derived from national agricultural and trade accounts, are often used to provide an estimate of food availability from which consumption can be estimated (*7*). A key strength of this approach is that the same methodology can be applied to most countries providing coverage and standardisation. Its weakness is that it does not directly measure consumption of individuals and adjustments have to be made for waste (*8*). Also, it focuses on primary commodities and not the processed and composite foods that are eventually consumed. This is a particular issue for meat products because of the differential health effects of processed and unprocessed meat (see below) (*9*).

Using food balance sheet data, the average global consumption of all meat has been estimated to be 122 g d^{-1} (grams per day), of which a third each is pork and poultry, a fifth is beef and the remainder from sheep, goats and other animals (*1*) (Fig. 0). Consumption has plateaued and possibly even decreased in high-income countries while it has risen dramatically in many middle-income countries, especially in China and East Asia although not India, perhaps because of the long tradition of vegetarianism among some communities. The amount of meat consumed in Africa has remained relatively low on average and in a few countries has declined, although in some pastoral communities meat and dairy constitute a very large proportion of the diet (*10*). There have also been major changes in the types of meat consumed in many regions: typically, more chicken at the expense of beef, and more processed meats (*1*).

Micha *et al*. (*11*) recently collated 266 individual dietary surveys from 113 countries to estimate the global consumption of red meat and processed meat for the Global Burden of Disease (GBD) project. The 2010 global average per capita consumption of 42 g d^{-1} unprocessed red and 14 g d^{-1} processed meat (which includes both red and white meat) hides great regional differences, with high-income (60-91 g d^{-1}) and Latin American (27-44 g d^{-1}) countries eating the most, and Africa (7-34 g d^{-1}) and Asia (4-7 g d^{-1}) the least. Food balance sheets from the same year indicate higher red meat consumption (~68 g d^{-1}, after adjusting for waste) although this includes some processed meat (*8*). Considering the different methodological assumptions, the two approaches agree reasonably well.

A well-established empirical relationship known as Bennett's law (*12*), shows that as people become wealthier their diets change from being largely based on starchy staples to diets that incorporate increasing amounts of refined grains, fruit, vegetables, meat and dairy (*13*). The degree to which these food types become incorporated in diets depends on their relative costs. To project diets into the future, some researchers have adopted a statistical approach based on relationships such as Bennett's law and expected future economic growth. Such studies have suggested that the rise in wealth will lead to an increase in meat consumption of about 100% will occur between 2005 and mid-century (*14*). A different approach is to attempt to model the economic dynamics of the food system (typically using partial equilibrium models). A review of such models suggested growth in the demand for livestock products would increase by 62-144% (*15*) by mid-century. A major review by the Food and Agriculture Organization (FAO) of the United Nations (*16*), which in addition makes extensive use of expert judgement, projects an increase in the total quantity of meat consumed of 76% by mid-century. This includes a doubling in the consumption of poultry, a 69% increase in beef and a 42% increase in pork (*16*). Though differing in details, the various all agree that there will be a substantial increase in the demand for meat.

Several uncertainties may affect these projections, including socio-economic change, productivity growth and climatic drivers, and in the precise relationship between demand for meat and rising income in different geographical regions. Demand for meat has both an economic and cultural basis: understanding how societal norms and narratives concerning meat consumption will evolve is both important and challenging to quantify. But there is widespread agreement that most of the increase in meat consumption will occur in low and middle-income countries.

Drivers of meat consumption

Understanding the reasons why we purchase and consume specific types of food is critical if we seek to improve health and environmental outcomes. For a minority of people, there may be no alternative to diets very high in meat and other animal-sourced food. Nomadic pastoralists in desert and semi-desert environments and traditional Inuit communities in the Arctic can only farm or hunt animals, because they have limited opportunities to grow or purchase other types of food. In other populations many people are too poor to buy more than small amounts of meat. But for a large proportion of the global population, the price of meat today, relative to their average income, is less than it has ever been in history.

Many factors, in addition to price, influence decisions to consume meat. Innate food preferences probably evolved in an environment where food scarcity was a constant risk. An intrinsic desire for energy-dense and nutrient-rich food, such as meat, once promoted survival, but today may predispose us to the diseases of over-consumption (*17, 18*).

Biological factors interact with a variety of psychological determinants to shape diets. We make decisions about purchasing meat based not only on affordability but also on other factors, such as availability or convenience (to buy or cook) and its social and cultural value. The food we buy and share, influenced by our beliefs and values, is part of the way we construct our own identities. In addition to deliberative thinking, the sub-conscious mind, influenced by the force of habit and societal norms, influences patterns of meat consumption (*19*).

Economics and political economy also influence diets. Livestock constitute 40% of agricultural output by price and meat production, processing and retailing is a significant economic sector in most countries. The sector has considerable political influence and allocates large amounts of money to advertising and marketing. Lobbying from the meat industry was intensive during the formulation of US Dietary Guidelines, and civil society organisations claimed that this influenced eventual recommendations (*20*). Non-state bodies seek to influence policy on meat and other food types, often by developing alternative narratives that resonate with sections of the public. Issues raised include animal welfare, the idea of what is "natural", and how production systems accord with worldviews on economic equity and globalisation versus localisation. This complex of competing narratives contains and is influenced by public health and environmental policy concerning diets.

Effects on health

The main approach to estimating the impacts of meat consumption on long-term health is through prospective epidemiological cohort studies in which tens of thousands of participants report their dietary intakes, and their health is followed over many years to identify the associations between meat consumption and risk of disease. The results of these studies have to be interpreted with great care to allow for potential confounding factors. Meta-analyses are important, but will not be reliable if they combine results from dissimilar studies, and are subject to the same potential biases as the original studies (*21*). Randomized controlled trials in humans are extremely difficult to conduct, especially over more than a few weeks or months, so it is diffciult to measure the long term effects on health, while the interpretation of the human health significance of trials in non-human animals is difficult.

Meat is a good source of energy and a range of essential nutrients, including protein and micronutrients such as iron, zinc and vitamin B_{12}. It is possible to obtain a sufficient intake of these nutrients without eating meat if a wide variety of other foods is available and consumed (*22, 23*). However, in some low-income countries access to alternative nutrient-dense foods may be limited, therefore diets low in meat may have negative health impacts (*24, 25*). Approximately 35% of people in India are vegetarians but the impact of vegetarianism is not well documented, although there is some evidence that

Indian vegetarians have a slightly more favourable cardiovascular risk profile than non-vegetarians (*26*).

In high-income Western countries, large prospective studies and meta-analyses generally show that total mortality rates are modestly higher in participants who have high intakes of both red and processed meat than in those with low meat intakes, whereas no or moderate inverse associations have been observed for poultry (*27-30*). However, part of this may be due to the association of high meat intakes with other major risk factors such as smoking, alcohol consumption and obesity because the information needed to remove statistically the influence of these confounding factors may not be available.

The strongest evidence for an adverse effect of high meat intakes on health is for colorectal cancer (Fig. 2a). The World Health Organization's International Agency for Research on Cancer (IARC) has classified processed meat as carcinogenic to humans because of an association with colorectal cancer, and red meat is classified as probably carcinogenic to humans, again based mainly on evidence of links to colorectal cancer (*9*). IARC estimate that 34,000 cancer deaths per year worldwide are attributable to diets high in processed meat and if the reported associations with red meat were proven to be causal, then diets high in red meat could be responsible for 50,000 cancer deaths per year worldwide (*31*). The average intake of processed meat in Western Europe [26.4 g d^{-1}; (*11*)] would, based on the IARC analysis, lead to a 9% (95% CI 5-14%) increase in colorectal cancer risk. High intakes of processed meat may also increase the risk for stomach cancer, but there is no strong evidence that it increases the risk for other types of cancer (*32*).

Processed meat consumption also seems to be associated with risk for several other diseases, although the evidence is not conclusive. For example, a recent meta-analysis reported that high intakes of processed meat (but not unprocessed red meat) are associated with a moderate increase in the risk for mortality from cardiovascular disease (*27, 30*) (Fig. 2b). Some studies have also suggested that high intakes of processed meat are associated with an increased risk for other chronic diseases, such as diabetes (*33*), and with weight gain in adults (*34*). Few cohort studies have examined the associations of meat intake with health in non-Western countries. In high-income Western countries a lower meat intake may be a marker of a health-conscious lifestyle, but in low-income countries lower meat intakes are more likely to be markers of poverty and associated with other risk factors for poor health. In a pooled analysis of Asian studies, and a recent cohort study in Iran, meat intake was substantially lower than in the USA and was not associated with risk of overall mortality or mortality from cardiovascular disease or cancer (*35, 36*).

It is not yet understood how colorectal cancer risk is increased by high consumption of processed meat or red meat. Components in meat that might be carcinogenic include haem iron, N-nitroso compounds in many processed meats, and heterocyclic aromatic amines and polycyclic aromatic hydrocarbons, which are formed when meat is cooked at high temperatures (*9*). Several mechanisms could also underlie the observed association between high meat intakes and risk for cardiovascular disease. For example, red and processed meats might increase risk because they are usually rich in saturated fatty acids which raise low density lipoprotein cholesterol, and processed meat might also raise blood pressure because it is usually high in salt; other mechanisms could be involved, such as the generation of trimethylamine N-oxide from L-carnitine in meat (*33, 37*).

Further research is needed on the effects of meat on health in low and middle-income countries, and on the role of substitute plant foods, such as pulses. For US cohorts, several studies have found significantly lower risk of coronary heart disease (*38*), stroke (*39*), type 2 diabetes (*40*), and all-cause mortality (*41, 42*) in statistical analyses that model replacement of animal sources of protein, in particular red and processed meat, by plant sources of protein, such as nuts, pulses, and whole grains. Model estimates that included individual risk coefficients for meat and plant-based products found that transitioning from high meat to more plant-based diets might reduce global mortality rates by 6-10% if the associations modelled are causal (*43*).

Currently, various national and international bodies recommend an upper limit of meat consumption for maintaining good health. For example, the World

Cancer Research Fund recommends that people who eat red meat should consume less than 500 g a week and population average consumption should not exceed 300 g a week, in each case minimising the fraction that is processed meat (*44*). Other initiatives, such as the Global Burden of Disease project, suggest a desirable intake of no more than one 100-g portion a week to reduce the disease burden related to meat consumption (*2*).

We have concentrated here on the nutritional effects of meat on human health, but meat is also a potential source of various food-borne infections (*45*). Livestock may also act as reservoirs for pathogens that can also infect humans, a particular problem where humans and farmed animals come into close contact (*46, 47*). Furthermore, antibiotics are used widely in meat production (Fig. 4b), both as veterinary medicines and as growth promoters. There is serious concern that genes for antibiotic resistance may be selected in agricultural settings and then transferred to human pathogens (*48*).

Effects on the environment

The question of whether producing meat is more or less harmful to the environment than other food types is complex because of the variety of meat production systems, the fact that meat production may or may not compete for resources that could be used to produce other food types and because it depends critically on how harm to the environment is measured (*43, 49, 50*).

Over the past two decades multiple life-cycle analysis studies have sought to assess the greenhouse-gas (GHG) emissions of different types of meat production systems (*51, 52*). Meat produces more emissions per unit of energy compared with plant-based foods because energy is lost at each trophic level (Fig. 1a). Within types of meat, ruminant production usually leads to more emissions than non-ruminant mammals, and poultry less than mammals. The type of production system is important. Intensive rearing tends to produce fewer GHG emissions than more extensive systems per unit of output (although they can bring with them other important disadvantages, discussed below).

The most important anthropogenic GHGs are carbon dioxide (CO_2), methane and nitrous oxide (N_2O). Meat production results in the emissions of all three and is the single most important source of methane (*51, 53*). Using the composite measure of CO_2 equivalents (CO_2e), livestock production is responsible for approximately 15% of all anthropogenic emissions (*51*). But calculation of CO_2e coerces emissions of the three onto a common scale, which can be misleading because of their different residence times in the atmosphere: for CO_2 cumulative emissions are key while for methane it is the rate of emission (*54*) (Fig. 3b). Currently, livestock contributes approximately 5% of the nearly 37 GT (gigatonne) of CO_2 human activities add to the atmosphere each year. 3700 GT cumulative emissions are estimated to cause 2°C warming, therefore one hundred years of livestock CO_2 production at current rates would lead to a measurable but comparatively small increment to global warming (~0.1°C). Meat production currently adds 0.15 GT of methane and 0.0065 GT of N_2O to the atmosphere annually. If the climate system is allowed to reach equilibrium with this level of GHG emission and decay (which would take about a decade for methane and about a century for N_2O) then the earth would be 0.44°C warmer. When this equilibrium is reached, continued emissions of methane and N_2O at the same level do not result in further warming. CO_2 is different, as its effect on warming will grow as long as CO_2 releases continue, even if the emissions rate does not increase. These estimates suggest that meat production really matters in calculations of future global warming, but that distinguishing the effects of the different types of GHGs is very important for policy makers (*54*).

About 4% of all meat and 8% of beef are produced in grass-fed only, extensive systems (grass is also used as a feed source in mixed systems) (*55*). Grazing has a complex effect on carbon budgets: it can stimulate plants to allocate more resources below ground, which helps sequestration, and livestock excreta can promote plant growth and carbon fixation by making nitrogen more available to the next generation of plants (although some of this nitrogen is lost through N_2O emissions) (*51, 56*). But this has to be balanced against direct GHG emissions from animals, the indirect emissions caused by overgrazing and erosion, and alternative potential uses for the land, including for carbon sequestration via natural plant growth or afforestation. Major claims have been made for the potential of livestock production by grazing to be a major net benefit for climate change by promoting CO_2 storage (*57*); however, careful analyses have shown that the estimated benefits are highly locality specific and that at a global level the benefits are modest at best and outweighed by the emissions the animals produce (*56, 58, 59*). Grasslands do store carbon but the further amount they can sequester depends on how much they already hold and eventually sequestration stops when gains are balanced by losses due to leaching, microbial respiration and other processes. Poor management, natural events such as droughts or fires, and land use change can quickly release the carbon back into the atmosphere (*60*). Careful management of grassland systems can contribute to mitigating climate change but the net benefits are likely to be relatively modest.

Agriculture uses more freshwater than any other human activity and nearly a third of this is required for livestock (*61*) (Fig. 4a). Water used in livestock production is largely (87.2%) 'green water', i.e., rain and other precipitation that falls directly on the land (*4*). Though 'blue water' withdrawals for livestock production, from rivers, lakes and groundwater, are only 7% of greenwater use, they are particularly important because they compete more directly with other uses of water, including that needed for the maintenance of aquatic ecosystems. Water used for growing animal feed accounts for 98% of the total water footprint of livestock production, with livestock drinking water, service water and feed-mixing water accounting for only 1.1, 0.8 and 0.03% of the total water footprint respectively (*4*). The effects of 'blue water' withdrawals can have significant impacts on water resources, such as in the High Plains aquifer in the central USA, where increasing production of cattle fed with irrigated corn is resulting in severe aquifer depletion (*62*). Unlike GHG emissions, which have the same climatic effect irrespective of where they are emitted, the impact of water use depends on the water source, location and season during which water is used. There is also considerable variation in water footprint among types of meat and production systems, though on average beef farming is more than three times as water intensive as chicken production per kilogram of meat (*4, 63*).

Nitrogen and phosphorus in animal manure contribute to nutrient loads in surface and groundwater, harming aquatic ecosystems and human health (*64*). Manure lagoons used in intensive livestock production, which contain nutrients, toxins and pathogens, are a concentrated contamination risk for surface and ground waters (*65*). Diffuse nutrient loading from pastoral livestock production depends on stocking rates, proximity to water bodies and land management practices (such as the presence of vegetation strips along water bodies) (*66*). Given a particular level of meat production, using animal manure as a substitute for artificial fertilisers, which require large amounts of energy to manufacture, helps lower greenhouse gas emissions (though reducing the levels of GHG-intensive meat production is always a more efficient strategy).

The most significant direct way in which meat production affects biodiversity is through land conversion to agriculture (*3*) (Fig. 4c). This involves both conversion of natural habitats to grassland and grazing, and conversion to arable land to produce grain and soya for livestock consumption. De Sy and colleagues (*67*) estimate that ~71% of rainforest conversion in South America has been for cattle ranching and a further ~14% for commercial cropping, including soya for animal feed (pastureland is often subsequently converted to cropland) (*68*). In the past 20 years, exports of soya from South America to China (and other countries) have increased dramatically and it now constitutes one of the largest international commodity flows (Fig. 1b). Livestock production also impacts biodiversity through overgrazing, with especially deleterious impacts in drylands (*69*). These ecosystems would have been grazed by wild herbivores, but the much higher offtake from livestock changes and reduces plant species diversity. The reduced plant cover and trampling on slopes leads to soil erosion and to further biodiversity loss. There has been considerable study of what combinations of wildlife and livestock densities best promote biodiversity in different ecological settings and in some cases where native herbivores are no longer present, or extinct, livestock can help or be essential to maintain natural ecosystems (*70*). But in many developing countries the understandable pressures from poor people needing to produce food lead to a vicious circle of unsustainable overgrazing and an increasing demand for grazing land.

Livestock production may also affect biodiversity through shared diseases. For example, lions in the Kruger National Park in South Africa are threatened by bovine TB which they contract from the buffalo they eat which, in turn, are infected by domestic livestock (*71*). But these effects need not always be negative. The global elimination of rinderpest was carried out to protect livestock yet wild ungulates also benefit from the eradication of this disease (*72*).

Changing diets

Studies of how people justify to themselves the consumption of meat show that believes that it is 'natural, normal, necessary, or nice' explains the large majority of variance in consumption (*73*). Precisely because meat consumption is a 'normal' part of the diet, often the routine centre of the main meal, the 'choice' to consume it goes largely unexamined. However, social norms can and do change and this process can be aided by the coordinated efforts of civil society, health organisations and government, as has been observed in the case of smoking cessation.

There are growing calls for government to intervene with changes to economic, politicial and or legal systems that could transform the system of meat production, supply and distribution (*74*). It is uncontroversial that governments should act to prevent chemically or biologically contaminated food from reaching markets. Indeed some ancient religious prohibitions on eating certain types of meat may have arisen to reduce food poisoning (*75*). There is more controversy over the degree to which the state should use animal welfare (or other) considerations to limit the production and sale of certain types of meat. There are technical and philosophical challenges in assessing an animal's quality of life, complicated by the fact that often livestock breeds are the results of many generations of selection for economically important traits that may lead to correlated effects on welfare (*76*). States also intervene to protect certain wild animals from hunting for food, often a contentious issue for example where consumption of 'bush meat' is culturally engrained. All developed and many developing countries have legislation that prohibits the production and sale of certain types of meat, based on non-economic animal rights or conservation considerations, but there is no consensus on their strictness.

A further consideration is the tension between state-sponsored interventions in the food system and free trade. Under World Trade Organization rules, and embodied in most trade agreements, governments are allowed to restrict meat imports for reasons of food safety, as well as to protect local farming from exogenous livestock disease. What is not allowed is for protectionist tariffs to be imposed, using these reasons as an excuse. For example, Samoa was forced to reverse a ban on fatty meat imports introduced as an anti-obesity measure (*77*). Current debates about whether chlorine-washed poultry could in the future be imported into the European Union (EU) illustrate these complexities (*78*). This procedure is currently banned in the EU, which has a different philosophy for ensuring the microbial safety of food, emphasising interventions earlier in the food chain.

Changing the behaviour of populations to reduce the demand for meat can be usefully considered through the lens of dual-process theory (Fig. 5) which considers the role of both conscious and non-conscious processes operating in parallel to influence food selection (*19*). While there is little direct evidence of the effectiveness of interventions to reduce demand for meat, there is a body of potentially relevant work which might inform how this could be implemented. One strand of potential interventions operates within the rational choice paradigm, based on reflective, conscious processing. For example, nutritional labelling is used to enable people to make healthier diet choices (*79*), though there is little evidence that labels focused on sustainability criteria change behaviour (*80*). Certification programmes run by the private sector or non-governmental organisations are another means of providing trusted evidence about welfare or environmental standards. While such interventions are likely to have modest impact in themselves, the lesson of tobacco control is that raising awareness of implications for health has been crucial in garnering support for policy changes (*81*).

Attempts to change diets through fiscal interventions also lies within a rational choice framework. Alhough not specifically aimed at meat consumption (and motivated more by economics than health), Denmark operated a tax on the saturated fat content of foods between 2011 and 2012 that raised prices of some meat products by 15% (*82*). Since its repeal, analyses of panel data have shown that the tax accompanied reductions in consumption of products high in saturated fat, including minced beef (*83*), and modelling of long term health outcomes suggests a reduction in non-communicable disease and premature mortality (*84*). Theoretical work has explored taxing food types in proportion to their GHG emissions (*85-87*). In these scenarios as meat prices rise substantial health and environment benefits are predicted to accrue, especially if supplementary measures are introduced to avoid negative effects for those on low incomes (Fig. 1c).

Some interventions depend for their effectiveness on unconscious behavioural processes and are largely automatic responses to environmental cues, with the result that people tend automatically to take a default option rather than actively seek out an 'opt-in' alternative. For example, there is some evidence that repositioning meat options to appear after, rather than before vegetarian options on menus or in buffets to make these items more prominent may increase the number of people selecting meat-free meals but more research is needed (*88*). Decreasing portion size of meat products in a restaurant has been shown to decrease meat consumption with no detrimental impact on customers perception of their restaurant experience, perhaps because the meat is a small part of the overall event (*89*). These approaches nudge consumers into changing their behaviour without necessarily requiring a conscious 'choice'. Behaviourally-motivated interventions are seen in some political philosophies as preferable to interventions in the market (*90*). Others worry about their effectiveness and the ethics of trying to manipulate population behaviour (*91*).

Concerns about the ethics and environmental consequences of meat consumption, have led to a rapid expansion in the development of meat substitutes. Significant new investment is going into products based on legumes and other plants, while novel substitutes based on a variety of microbial and plant substrates are attracting substantial venture capital (*92*). Not as advanced, but also receiving significant attention, is cultured meat developed in the light of recent advances in our understanding of muscle development (*93*). A new research challenge is to understand the consumer response to these foods and to assess the economic, labour, environmental and health consequences were they to be produced at large scale.

Conclusions

Future changes in global meat consumption will have major effects on the environment and human health, as well as on the economics of the food system. It is difficult to envisage how the world could supply a population of 10 billion or more people with the quantity of meat currently consumed in most high-income countries without substantial negative effects on environmental sustainability. Current evidence suggests that increased consumption of meat, especially red and processed meats, will adversely affect public health. There are data suggesting that in some high-income countries per capita meat consumption is plateauing or beginning to decline and that "peak meat" may have passed. But consumption is increasing in many other countries, including those with large populations such as China.

There is need for more evidence about the effectiveness of different interventions seeking to affect people's conscious and unconscious food purchasing and consumption practices. This will require a better understand of how individual actions are influenced by societal norms and the structure of the food system within which individuals are embedded. The multitude of factors that influence the price and availability of meat, and how it is processed and marketed, determine a socioeconomic landscape that profoundly affects, and is affected by, norms and behaviours. The existence of major vested interests and centres of power makes the political economy of diet change highly challenging.

History suggests that change in dietary behaviours in response to interventions is slow. But social norms can and do change and this process can be aided by the coordinated efforts of civil society, health organisations and government. However, it is likely to require a more complete understanding of the impact of meat consumption on health and the environment and a licence from society for a suite of interventions to stimulate change.

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Figure Legends

Figure 0. Total consumption of meat (in million tonnes) in different regions and (inset) globally (*1*).

Figure 1. The economics of meat production. (a) The value of livestock (globally and by region) as a proportion of total agricultural value in 2014 (numbers above bars are absolute values in billion dollars adjusted for purchasing parity power using constant 2006 dollars) (*1*). (b) Growth of exports of soya feed for livestock from South America to China (*1*). (c) Predicted change in price and consumption of different food types after the introduction of a globally uniform tax related to greenhouse gas emissions. Meat products are some of the most strongly affected food types (*94*).

Figure 2. Meat and health. (a) The relative risk of colorectal cancer as a function of average processed meat intake (from (*95*)). (b) The relative risk of cardiovascular death as a function of average processed meat intake (from (*27*))

Figure 3. Meat and climate change. (a) Greenhouse gas emissions from the production of different food types in 2005/7 and projections for 2050 (assuming an emissions pathway that would keep global temperatures below 2°C). The y-axis is the percentage of total GHG emissions. Animal-sourced foods are the major source of food-system GHGs and their relative importance is likely to increase in the future (*43*). (b) The three major greenhouse gases have quite different effects on climate. The figure shows

the effect on climate warming of each gas if emissions at the current rate produced by livestock operations were introduced in Year 0 and thereafter held fixed indefinitely (methodology from (*54*)). The warming due to methane is substantial and rises quickly, but due to the gas's short residence time in the atmosphere ceases growing after about two decades, whereas the warming due to carbon dioxide continues to grow throughout the two centuries shown, and indeed would continue to grow indefinitely so long as emissions continue. The warming due to nitrous oxide has begun to level off at the end of the two centuries, and grows little in subsequent years. Note that while the warming in response to a fixed methane emission rate levels off rather quickly, an increase in the rate of methane emissions, caused by an increase in livestock production, would still cause proportionate increases in the methane-induced warming.

Figure 4. Meat and the environment. (a) The proportion of global freshwater withdrawals (out of a total of 4001 km^3 yr^{-1}) used for agriculture (livestock & arable), industry and energy, and in the municipal and domestic sectors. Data from FAO AquaStat 2016 (http://www.fao.org/nr/water/aquastat/main/index.stm). (b) Use of antibiotics in agriculture in different countries (expressed as mg antibiotics per kg meat PCU [population correction unit] to allow comparison). Data from (*96*). (c) Fate of deforested land in Matto Grosso, Brazil; small area conversion refers to areas less than 25 ha (*97*).

Figure 5. The dual process model of motivation and interventions that target automatic and deliberative decision-making. Example of (i) situational factors are events, moods, and emotions; (ii) the environment are the layout of products in a shop or the marketing experienced by an individual; and (iii) personal characteristics are factors such as values, beliefs, and traits such as self-restraint or impulsivity.

Fig. 0

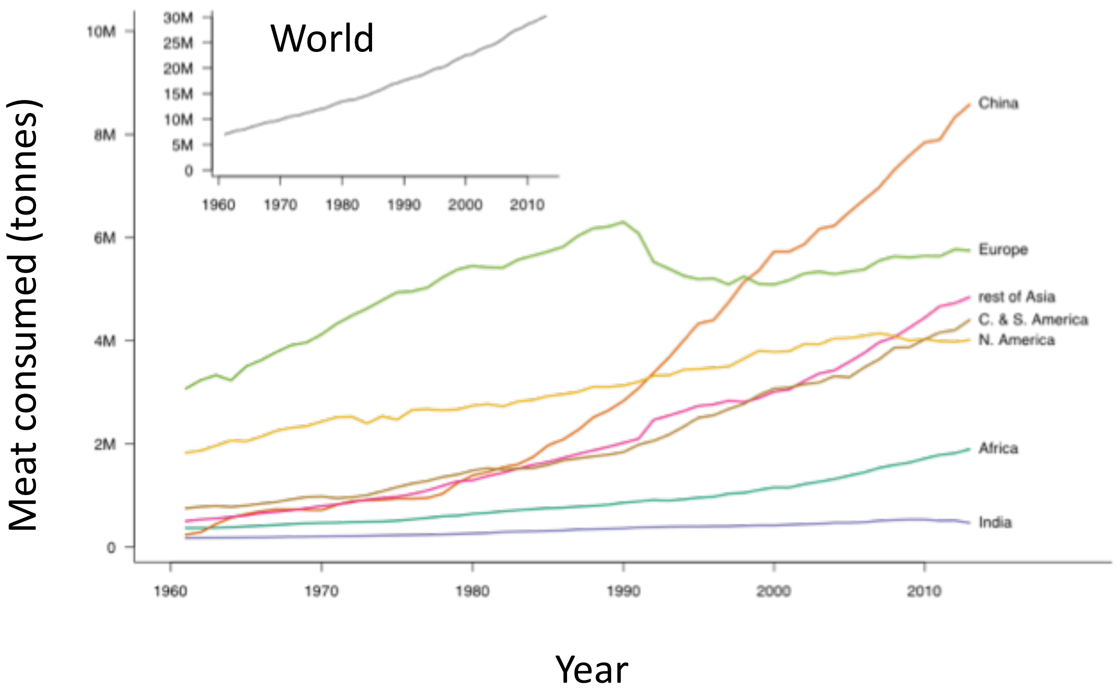
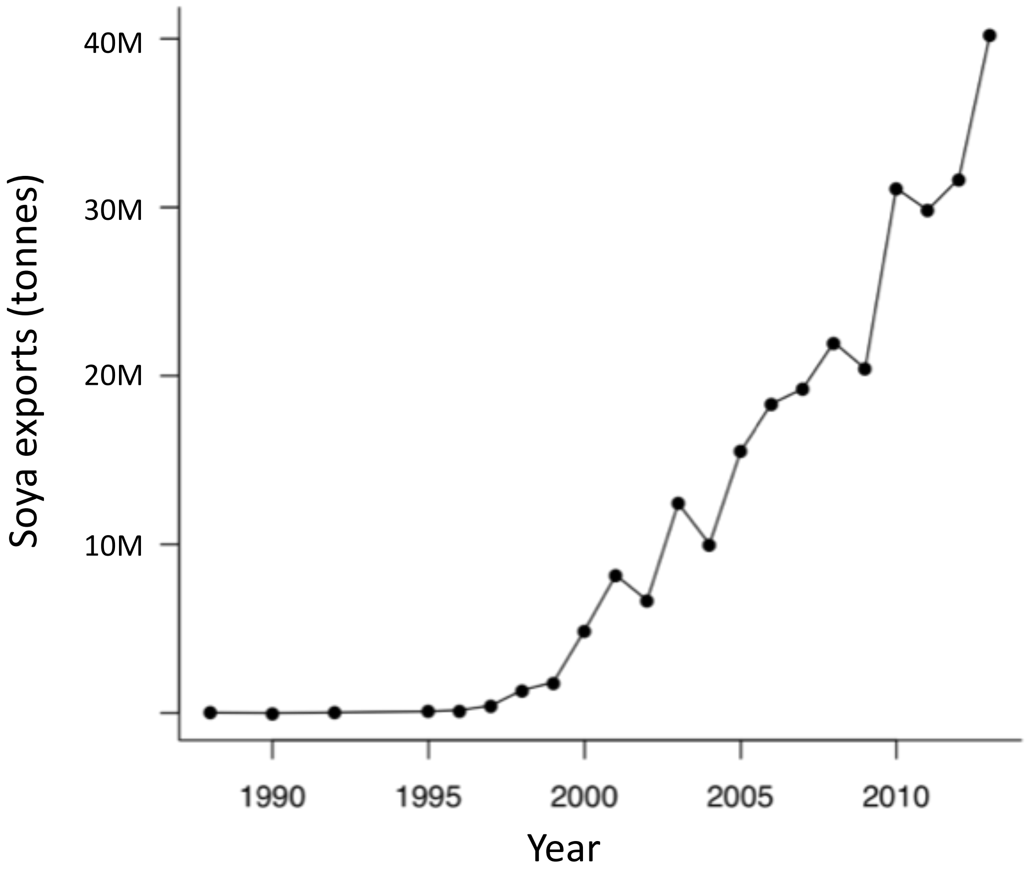

World
30M
25M
20M
15M
10M
5M
0
1960
1970
1980
1990
2000
2010
10M
8M
6M
4M
2M
0
China
Europe
rest of Asia
C. & S. America
N. America
Africa
India
Meat consumed (tonnes)
Year

Fig. 1a


Livestock as proportion value of agriculture
0.5
0.4
0.3
0.2
0.1
0.0
$887B
$53B
$126B
$128B
$185B
$181B
$69B
$119B
World
Africa
rest of Asia
C. & S. America
China
Europe
India
N. America
Region

Fig. 1b



40M
30M
20M
10M
Soya exports (tonnes)
1990
1995
2000
2005
2010
Year

Fig. 1c

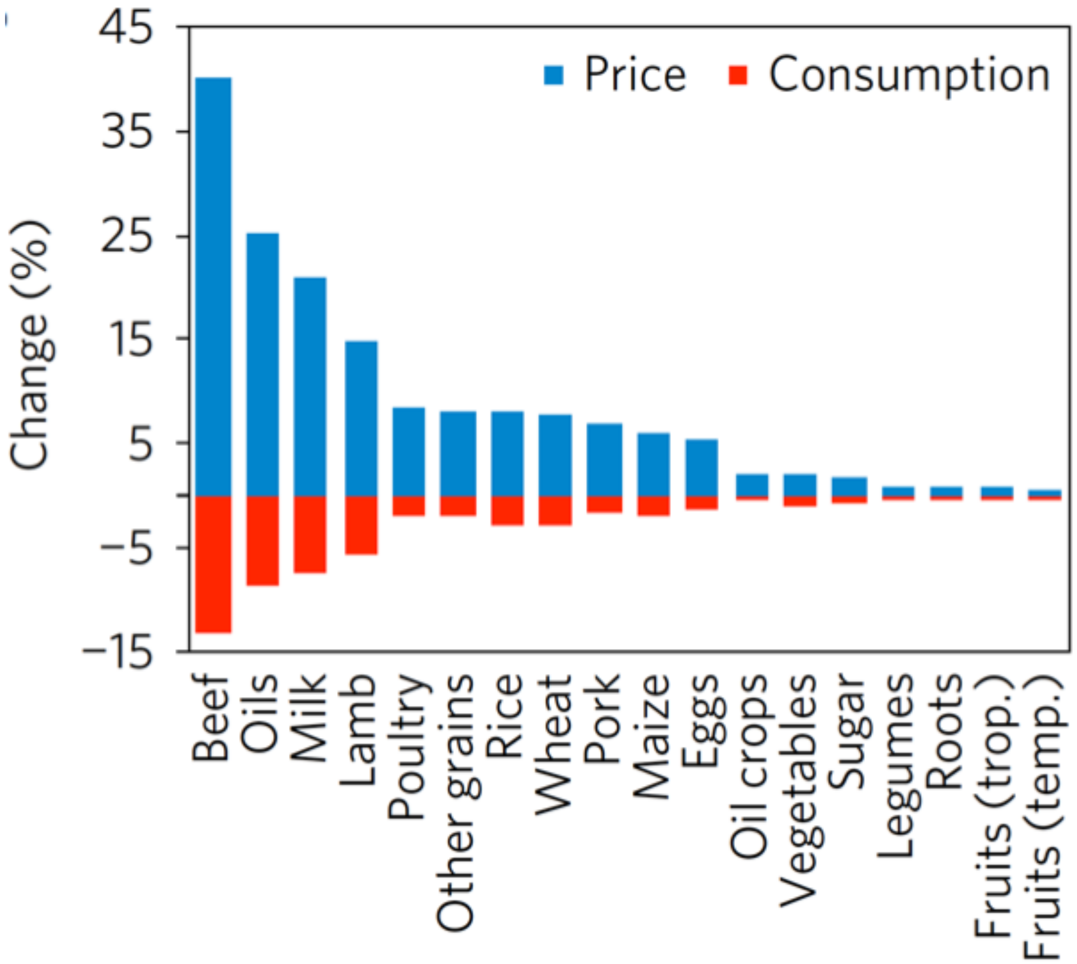
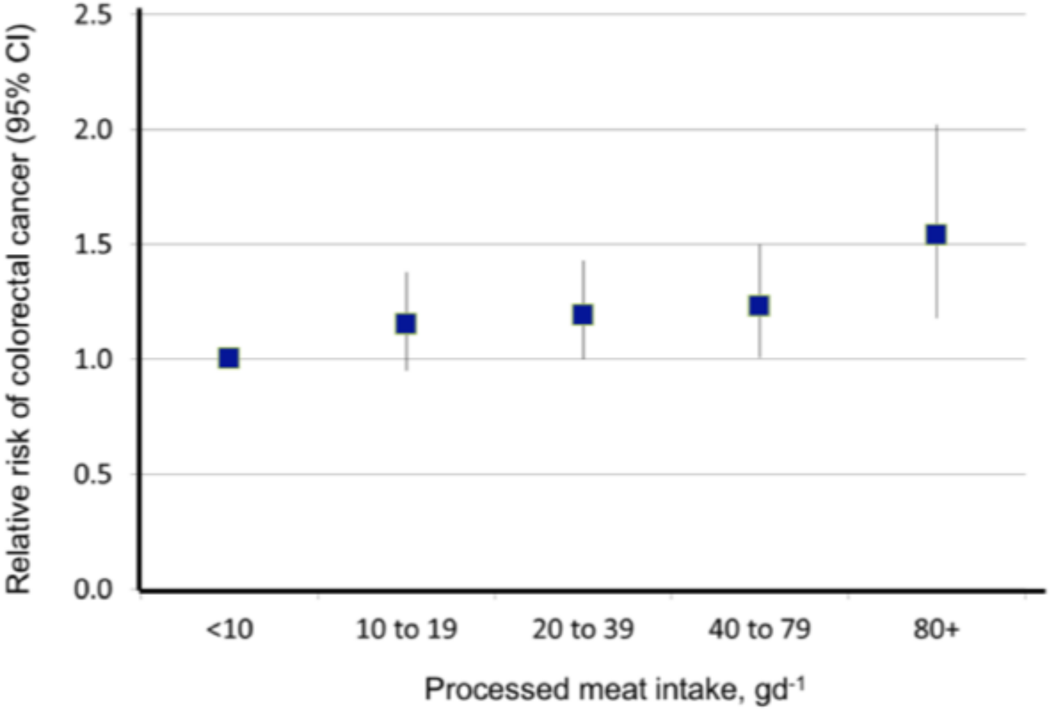
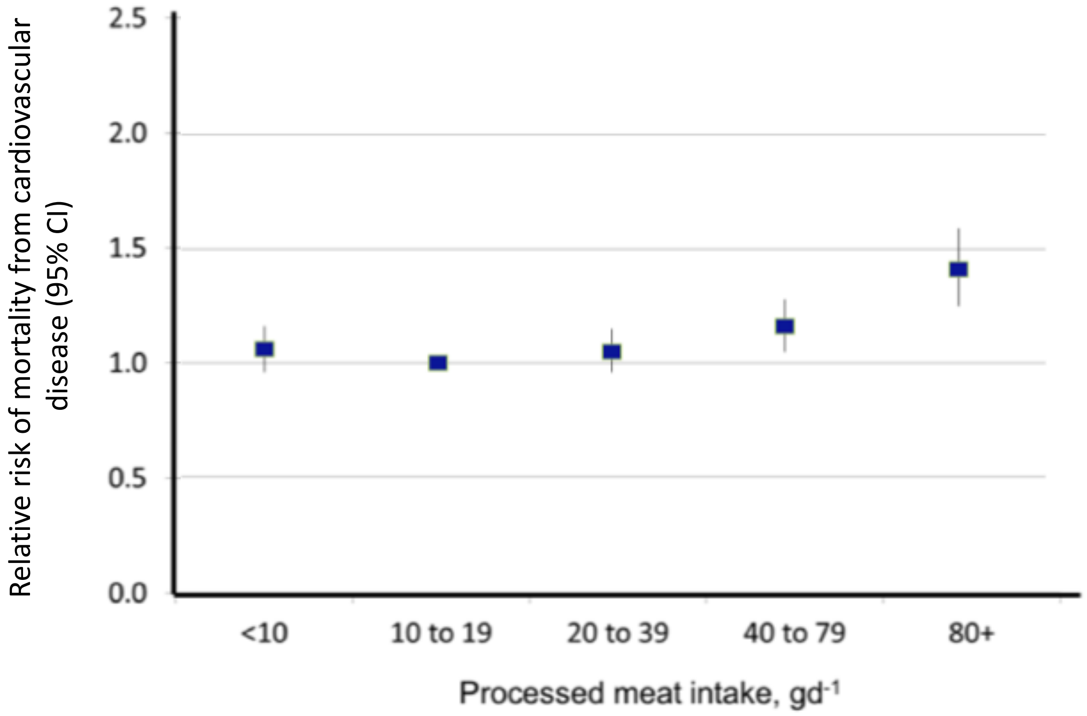

Change (%)
45
35
25
15
5
−5
−15
Price
Consumption
Beef
Oils
Milk
Lamb
Poultry
Other grains
Rice
Wheat
Pork
Maize
Eggs
Oil crops
Vegetables
Sugar
Legumes
Roots
Fruits (trop.)
Fruits (temp.)

Fig. 2a



Relative risk of colorectal cancer (95% CI)
2.5
2.0
1.5
1.0
0.5
0.0
<10
10 to 19
20 to 39
40 to 79
80+
Processed meat intake, gd-1

Fig. 2b



Relative risk of mortality from cardiovascular disease (95% CI)
2.5
2.0
1.5
1.0
0.5
0.0
<10
10 to 19
20 to 39
40 to 79
80+
Processed meat intake, gd-1

Fig. 3a

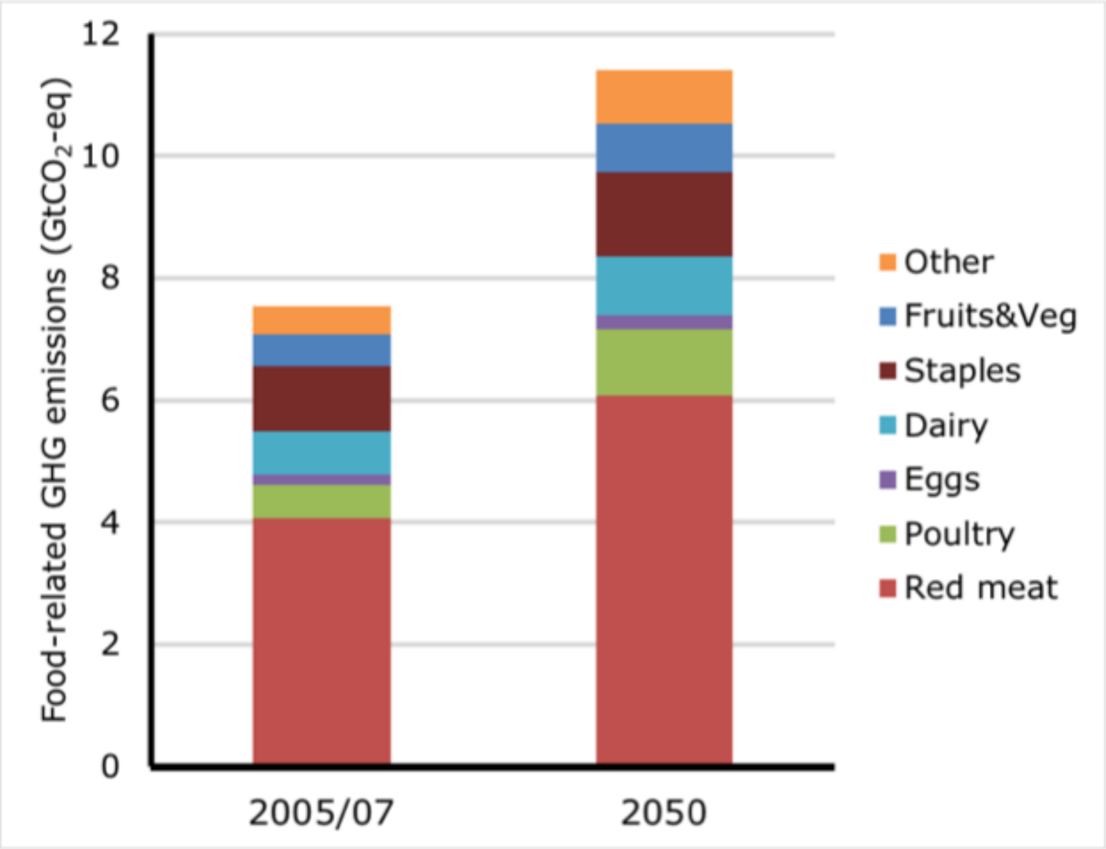
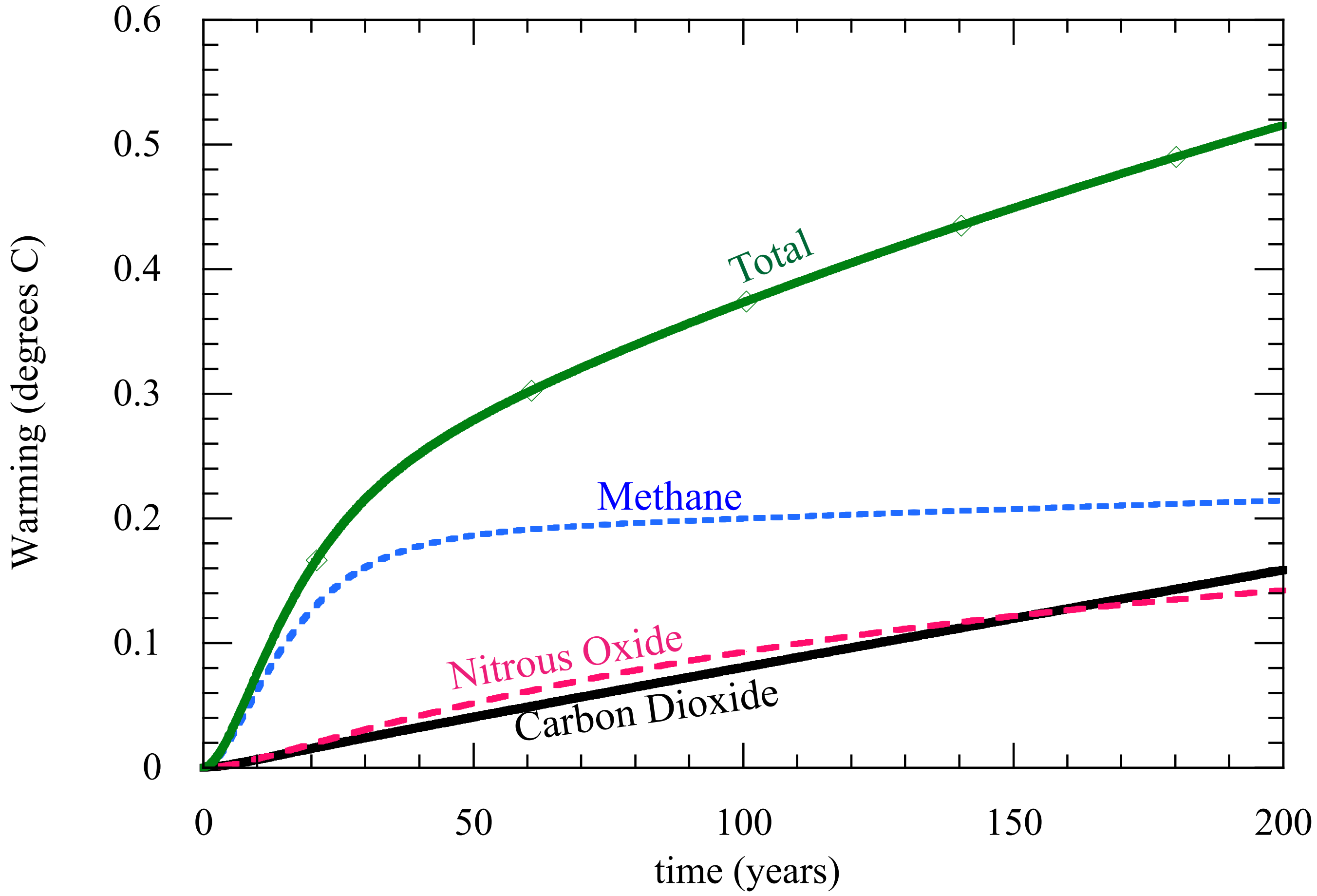

Food-related GHG emissions (GtCO$_2$-eq)
12
10
8
6
4
2
0
2005/07
2050
Other
Fruits&Veg
Staples
Dairy
Eggs
Poultry
Red meat

Fig. 3b



0.6
0.5
0.4
0.3
0.2
0.1
0
Warming (degrees C)
Total
Methane
Nitrous Oxide
Carbon Dioxide
0
50
100
150
200
time (years)

Fig. 4a

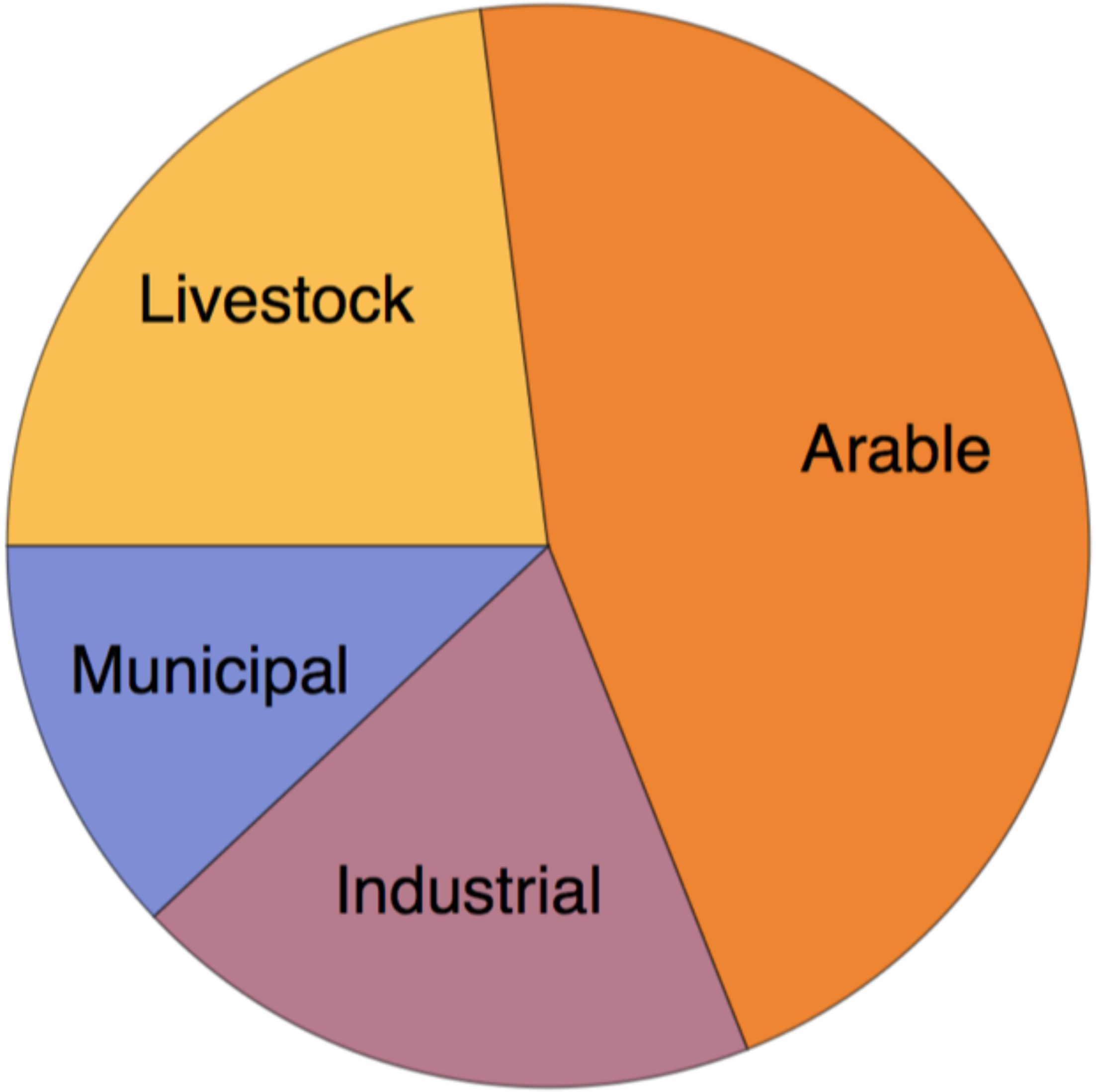


Fig. 4b

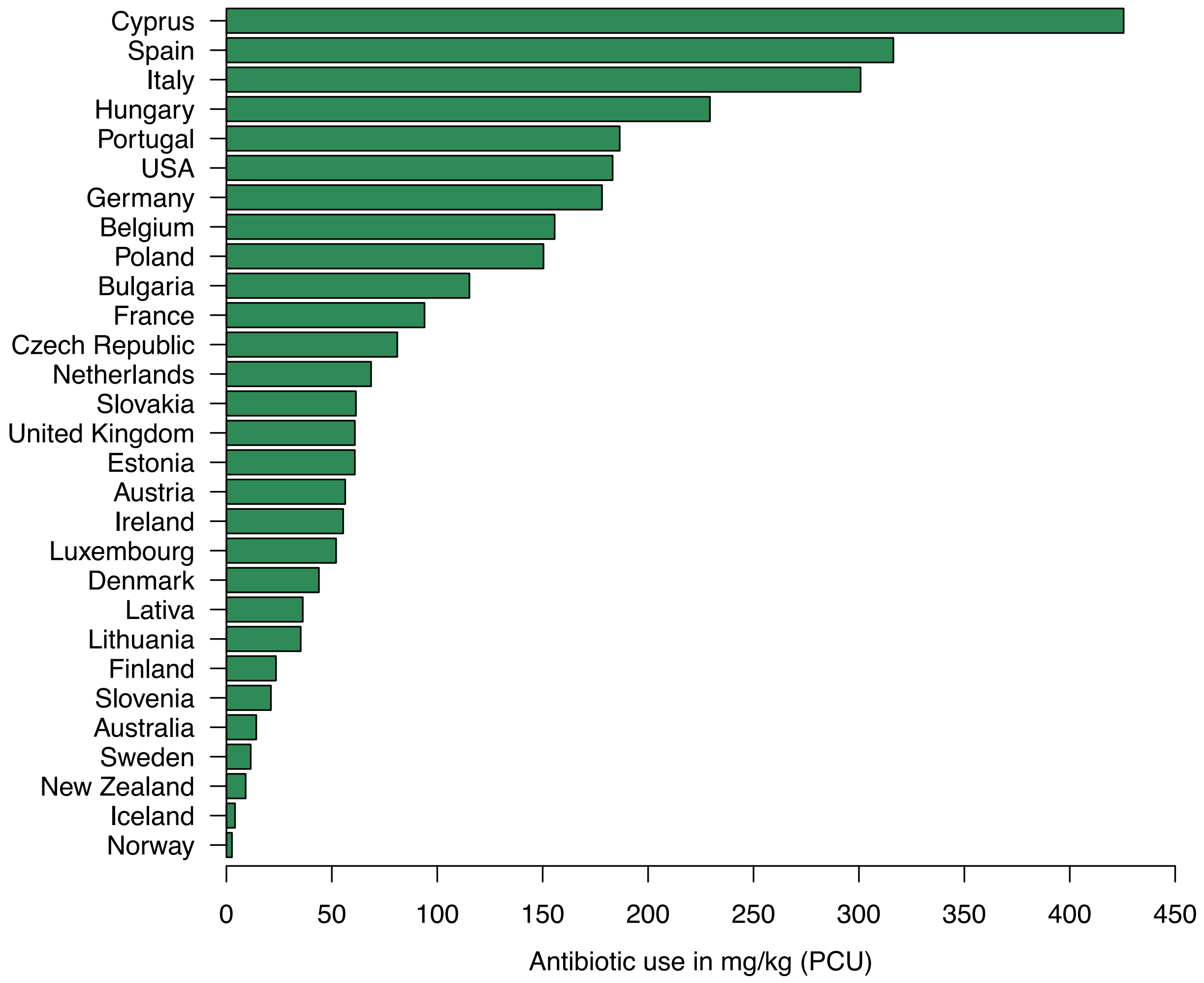
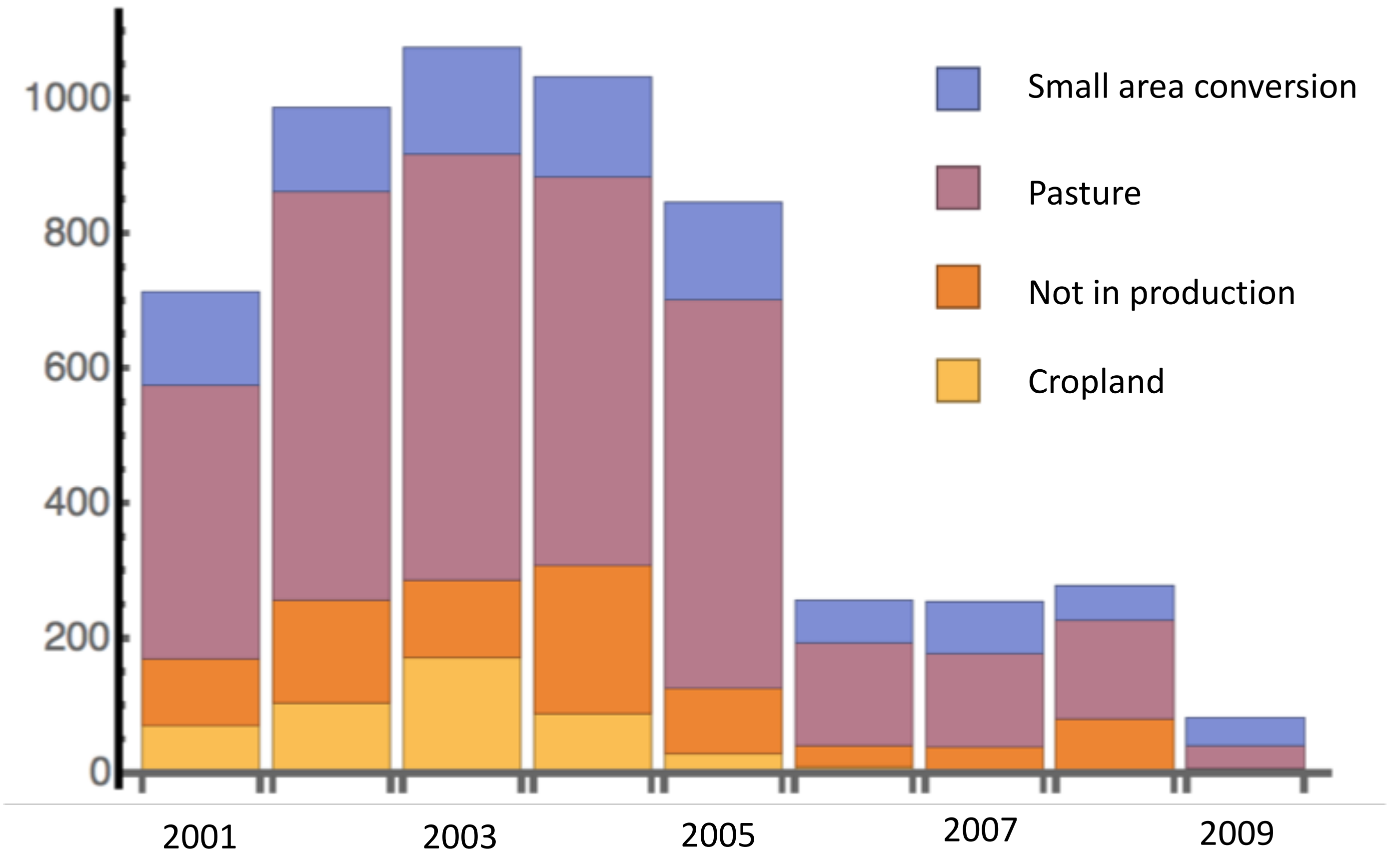
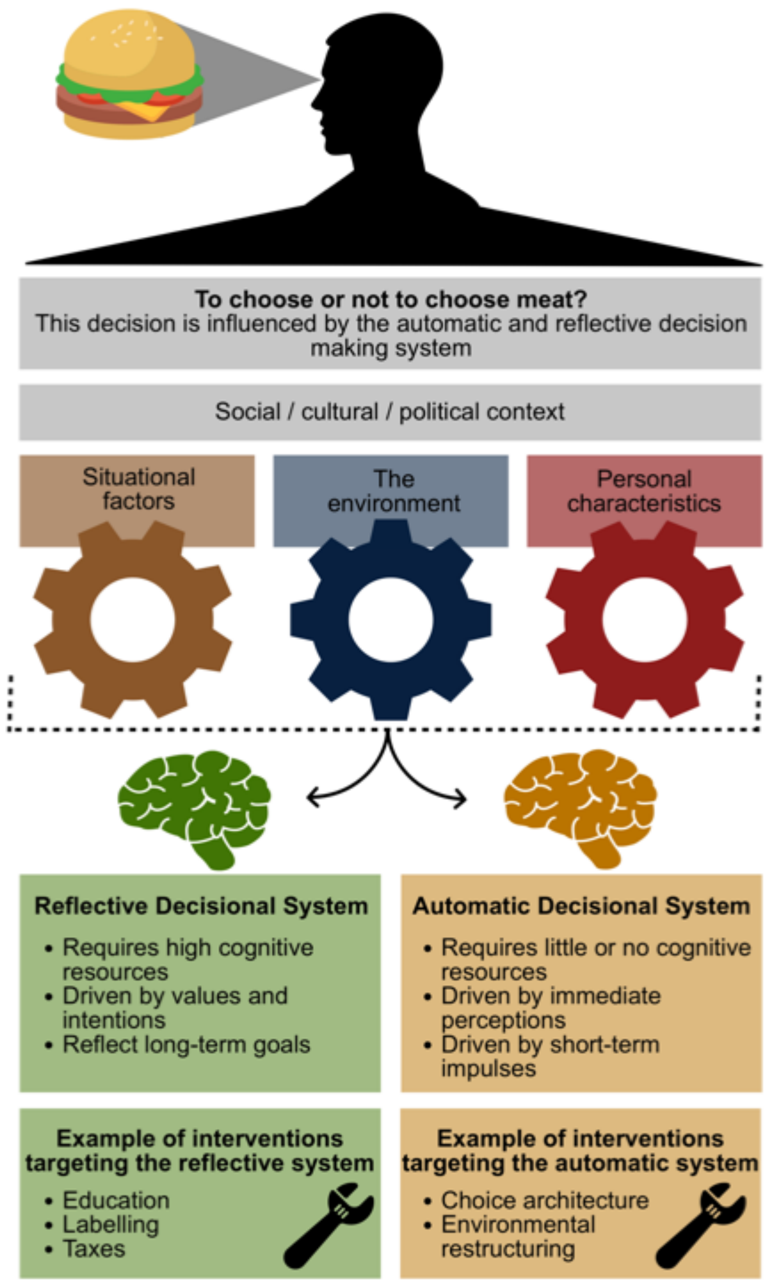

Cyprus
Spain
Italy
Hungary
Portugal
USA
Germany
Belgium
Poland
Bulgaria
France
Czech Republic
Netherlands
Slovakia
United Kingdom
Estonia
Austria
Ireland
Luxembourg
Denmark
Lativa
Lithuania
Finland
Slovenia
Australia
Sweden
New Zealand
Iceland
Norway
0
50
100
150
200
250
300
350
400
450
Antibiotic use in mg/kg (PCU)

Fig. 4c



Small area conversion
Pasture
Not in production
Cropland
1000
800
600
400
200
0
2001
2003
2005
2007
2009

Fig. 5



To choose or not to choose meat?
This decision is influenced by the automatic and reflective decision making system
Social / cultural / political context
Situational factors
The environment
Personal characteristics
Reflective Decisional System
• Requires high cognitive resources
• Driven by values and intentions
• Reflect long-term goals
Automatic Decisional System
• Requires little or no cognitive resources
• Driven by immediate perceptions
• Driven by short-term impulses
Example of interventions targeting the reflective system
• Education
• Labelling
• Taxes
Example of interventions targeting the automatic system
• Choice architecture
• Environmental restructuring