Global Food Security ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Global Food Security

journal homepage: www.elsevier.com/locate/gfs

Eating meat: Constants and changes☆

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ARTICLE INFO

Article history:
Received 5 June 2014
Accepted 19 June 2014

Keywords:
Carnivory
Meat production
Environmental impact
Environmentally sensitive production
Future meat consumption

ABSTRACT

Eating meat has been an important component of human evolution and rising meat consumption has made a major contribution to improved nutrition. Expanding the current practices of meat production would worsen its already considerable environmental consequences but more environmentally sensitive ways of meat production are possible. Although they could not match the current levels of meat supply, they could provide nutritionally adequate levels worldwide. This would mean a break with historical trends but such a shift is already underway in many affluent countries and demographic and economic factors are likely to strengthen it in decades ahead.

1. Introduction

Science is more than an impartial quest for a proper understanding of realities and for a better guidance through the complexities of modern decision-making: it is a social construct and hence not immune to being partial and getting deployed (sometime subtly, other time quite bluntly) in the service of various preferences and deeply-held opinions. Meat eating is a perfect example of what happens when advocacy and promotion of absolute stances displace impartial judgments of a complex reality. On one hand scientific evidence (excessively high environmental cost of meat, brutality of animal treatment and slaughter) is called on to support the case for meatless diets, on the other hand modern research-driven agriculture produces more feed crops than food crops to support record levels of meat production.

2. Carnivory and its consequences

There is absolutely no doubt that human evolution has been closely linked in many fundamental ways to the killing of animals and eating their meat. Our digestive tract is too short and too simple to serve an obligatory herbivore; enzymes it contains facilitate meat digestion; there is no need to invoke the expensive tissue hypothesis in order to affirm that meat consumption has aided higher human encephalization and better physical growth. Similarly, cooperative hunting of large animals helped to promote socialization and the development of language; and the history of sedentary Old World societies was closely linked with the domestication of animals and eating of their meat whose consumption was both a sign of higher social status and a source of dietary preferences and taboos. And modern science explained the consequences of protein deficiency, particularly in children, and it confirmed meat's nutritional advantages as an excellent source of all essential amino acids, lipids and important micronutrients.

We are, indubitably, an omnivorous species with a generally high degree of preferences for meat consumption, and only environmental constraints and cultural constructs of pre-industrial societies led to lower meat consumption, a shift that was reversed in all modern affluent societies. Higher meat consumption has been a key component of a worldwide dietary transition that was enabled by industrialization and urbanization, first in Europe and North America, in recent decades in modernizing economies of Asia and Latin America. Global meat production rose from less than 50 million tonnes (Mt) in 1950 to about 110 Mt in 1975; it doubled during the next 25 years, and by 2010 it was about 275 Mt, prorating to about 40 kg/capita, with the highest rates (US, Spain and Brazil) in excess of 100 kg/capita (all rates are for carcass weight).

But this has been a rather costly achievement because mass-scale meat production is one of the most environmentally burdensome activities, with impacts ranging from groundwater (contaminated with nitrogen leached from fields used to grow animal feed) to the global atmosphere (with CH_4 from enteric fermentation as a major contributor of a greenhouses gas with warming potential much higher than that of CO_2), and from soil erosion due

☆This essay summarizes some findings from my book *Should We Eat Meat? Evolution and Consequences of Modern Carnivory* (Wiley 2013) which contains detailed and extensively referenced accounts of feeding efficiencies, meat consumption rates, environmental burdens of meat production and potential meat substitutions. Detailed information on global food and feed harvests and on the availability of crop residues can be found in: Smil, V. 2013. *Harvesting the Biosphere: What We Have Taken from Nature* (MIT Press). One of the world's most notable dietary transitions whose outcome demonstrates the benefits of moderate meat consumption is surveyed in: Smil, V. and K. Kobayashi. 2011. *Japan's Dietary Transition and Its Impacts* (MIT Press).

http://dx.doi.org/10.1016/j.gfs.2014.06.001
2211-9124/

to tropical deforestation. Rising demand led to expanded traditional meat production in mixed farming operations (above all in the EU and China), to extensive conversion of tropical forests to new pastures (in Latin America) and to dominance of concentrated animal feeding facilities (for beef mostly in North America, for pork and chicken now worldwide except for Africa). This has created mass-scale feed industry based mainly on corn and soybeans (with added micronutrients and preventive doses of antibiotics), shortened production spans (just six to seven weeks for broilers, less than six months after weaning for pigs), and affected animal welfare.

There are at least five major categories of undeniable burdens created by modern mass-scale meat production that relies on concentrated animal feeding. The first one is a fundamental reorientation of traditional agricultures dominated by growing food crops to monocultures of animal feed with attendant increases in soil erosion, and intensified interference in water and nitrogen cycles. The second one is inherently inefficient conversion of phytomass to edible zoomass, particularly so in the case of ruminant meats, the most environmentally expensive food. The third one is generation of huge volumes of waste by centralized feeding operations that preclude near-complete nutrient recycling to crop fields. The fourth one are the emissions of greenhouse gases, both due to the cultivation of feed crops and to animal metabolism. And the fifth one is the treatment of animals in confinement (stressful conditions, impaired welfare) and some questionable ways of their slaughter.

Thinking about the road ahead we must recognize several fundamental realities. Solutions will not come from voluntary meatless diets, mass production of mock meat (transformed plant proteins) or muscle tissues cultured in bioreactors. Substituting meat intakes by consumption of other high-protein animal foodstuffs is of marginal help. At the same time, meat production based only on truly sustainable grazing, feeding of forages rotated with food crops, and maximum use of crop and processing residues is inherently limited and although, once it is reoriented toward producing less beef and more pork and chicken, it could supply a surprisingly large share of today's meat consumption (as I will show, close to 70% of 2010 supply) it will not be able to satisfy global demand anticipated for 2030 and even less so for 2050. Innovations and productivity improvements alone cannot prevent further increases in already significant environmental burden of meat production and to reduce them we will also need to moderate our meat consumption.

3. Meatless diets, mock and cultured meat

Commitment to vegetarianism (to say nothing about strict veganism) will not fundamentally affect future demand for meat. Insistent promotion of nutritional and environmental benefits of meatless diets has not had intended mass impacts. A much publicized anticipation illustrates the point: in 1975 in *The Book of Tofu*, Shurtleff and Aoyagi predicted that within 10–20 years the sources of America‘s dietary protein will be completely reversed, with 80% originating in plant foods, and that tofu shops will spread around the country, making an invaluable contribution to better life on our planet. But animal foods still supply about 65% of America's dietary protein, and small tofu shops have never sprouted in America, but have been rapidly disappearing even in Japan. Studies show that all forms of vegetarianism (ranging from those allowing consumption of dairy products and eggs to strict veganism) are practiced by no more than 2–4% of population in any Western society and that long-term (at least a decade) or lifelong adherence to solely plant-based diets has prevalence lower than 1%.

Moreover, there are no obvious population-wide advantages to vegetarianism. The world's longest living population is far from being vegetarian: Japan's per capita food supply now averages more than 50 g/day of animal protein, with about 40% coming from seafood and 30% from meat, and three of Europe‘s countries with the highest life expectancy – Sweden, Norway and Iceland – have diets with substantial quantities of meat and a large amount of dairy products. Voluntary population-wide abstention from eating meat is thus extremely unlikely and even if practiced it would have no significant health benefits compared to moderate consumption of meat and other animal foodstuffs.

Cultured meat will not be produced on a mass scale anytime soon and a long history of mock meat makes it unlikely that it will be anything but a marginal choice. An increasing array of vegetarian mock meats (shaped as burgers, patties, cutlets, nuggets, bacon, sausages etc., all basically reconstituted soy and wheat proteins and mushrooms) has been available for decades but the value of their recent US sales has been less than 0.2% of annual meat sales, hardly a promise of capturing a substantial market share in the near future. Promise of in vitro meat is also decades-old but recent reports of a near-perfect cultured hamburger make clear how challenging and how costly will be the process from experimental production of a few hundred grams to about 15 Mt/year that would be needed to capture just 5% of today's global meat market.

While veganism and mock and cultured meats will not prevent future rise of meat demand it is certain that global average per capita meat consumption will not rise to North American or the EU levels, and there is actually a high probability that the current consumption rates in affluent countries will decline. Long-term models are notoriously error-prone: think about a 30-year forecast of any consumption variable done in 1980 for China (four years after Mao's death) or the USSR (11 years before its collapse). What is much more useful than offering forecasts based on economic growth or anticipated consumption patterns is to estimate how much meat could be produced with minimized environmental impact and in a truly sustainable way.

The baseline quantity would be produced without any cultivation of feed grains (cereal and legume) only by combining available crop and processing residues with more environmentally-sensitive use of pastures. The next step is to ascertain what share of the current meat output could be replaced by non-meat animal protein produced with lower environmental burden. Obviously, these calculations are just the best approximations of relevant global totals but because my assumptions consistently err on a conservative side they provide a revealing reality check on what is possible.

4. Grazing, crop and processing residues, and forages

Most of the world's grasslands have been already degraded by overgrazing and that is why I assume that the pasture-based meat production should be reduced by an average of 25% in all low-income countries and by at least 10% in affluent countries, and that in order to prevent further deforestation and loss of biodiversity there should be absolutely no additional conversion of forests to grasslands in Latin America, Africa and Asia. These measures would reduce pasture-based global beef output to about 30 Mt/year (compared to more than 50 Mt in 2010) and mutton and goat meat production to about 5 Mt (compared to more than 10 Mt in 2010). An alternative way to calculate the maximum safe grazing contribution is to assume 25% of all currently grazed area should be set aside to recuperate and the remainder (2.5 billion ha) should support no more than about half a livestock unit (LU, about 250 kg of live weight; EU limit is 1 LU/ha, Brazilian pastures support 1 LU/ha, 0.5 LU/ha is common in sub-Saharan Africa). With average

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annual 10% off-take rate and 0.6 conversion rate from live to carcass weight that would yield about 40 Mt/year from grazing, confirming the first derivation.

Restrictions should also apply to the feeding of crop residues: where their yields are low and the land is erosion-prone they should be recycled to the greatest practicable degree which means that commonly 30–60% of them should not be harvested. The best use of cereal straws, by far the most abundant class of crop residues, is as a partial replacement of high-quality forages, particularly leguminous cover crops (alfalfa, clovers, vetches). If only 10% of the world's arable land (about 130 Mha) were used to grow such forages (in rotations with cereals and tubers), then even with a low yield (just 3 t/ha of dry phytomass) they would produce about 420 Mt of feed (fresh cuttings, silage or hay). Diverting the same mass of crop residues for feeding would have few negative impacts because 420 Mt represents less than 25% of the residual phytomass that would have been produced in 2010 even after assuming that no grains were cultivated for feed. Feeding 840 Mt of forages and residues would, even with a very conservative conversion ratio of 1 kg meat (carcass weight) requiring 20 kg of dry matter, produce at least 40 Mt of ruminant meat.

Processing residues (mainly by-products of food grain milling and oilseed extraction) are commonly used for feeding. At least 270 Mt of grain milling residues and 310 Mt of oil cakes were produced in 2010. But if soybean cultivation were limited only to food production the worldwide output of oil cakes would be only about 160 Mt/year. After adding by-products from sugar and tuber processing, and commercial vegetable and fruit canning and freezing, the mass of nutritious residues available as animal feed would be about 400 Mt. Dividing this feed between broilers and pigs, and assuming feed: live weight conversion ratios of, respectively, 2:1 and 3:1 and carcass weights of 70% and 60% of live weight) would yield about 70 Mt of chicken meat and 40 Mt of pork.

Combination of grazing with greatly reduced pasture degradation (40 Mt of ruminant meat), feeding forages and crop residues (40 Mt of ruminant meat) and converting highly nutritious crop processing residues (70 Mt chicken meat and 40 Mt pork) would thus produce annually about 190 Mt of meat. And the difference between this rational production and the actual 2010 meat output could be even smaller because I used very conservative assumptions and gains on the order of 5–10% could come from the combination of slightly more frequent rotations of cereals with leguminous forages, treating straws with ammonia to increase its nutrition and palatability, by more efficient use of food processing by-products and by elimination of some of the existing post-production meat waste.

Annual output of about 200 Mt of meat is thus an unassailably realistic total of global meat output achievable without any further conversion of natural ecosystems to grazing land, with conservative pasture management, and without any direct feeding of grains (corn, sorghum, barley), tubers or vegetables, that is, without animal feeds competing with food produced on arable land and requiring additional applications of fertilizers and other agrochemicals. The global total of 200 Mt of meat produced in environmentally more sensitive ways – with beef produced without grain feed and with concentrate feeds converted more efficiently to chicken and pork – would be equal to almost 70% of the actual 2010 meat output of about 290 Mt.

5. Other animal foodstuffs

And while other animal foodstuffs can never be thought of as truly interchangeable substitutes for meat, they are nutritionally equivalent in terms of protein, some provide protein without heavy lipid content (milk, yoghurt, eggs) or do so in combination with more desirable lipids (fish). Given the protein equivalence of animal foodstuffs, as well as high nutritional quality and gustatory appreciation of seafood, eggs and dairy products, as well as a well-documented possibility of changing dietary habits over time, it is natural to ask what share of today's meat consumption could be realistically displaced by higher intakes of other animal foodstuffs.

There are no fundamental obstacles to moderate displacement of meat by eggs and dairy products. Cholesterol in eggs would be a concern only with excessive consumption and separation of egg whites from yolks produces pure protein. Fully fermented cheeses contain no lactose and moderate consumption of milk and dairy products is not a population-wide concern even in societies with widespread lactase deficiency: Japan went from essentially no dairy consumption in 1945 to consuming more dairy products (by weight) than rice. Meat production equally divided among chicken, pork and beef would have weighted conversion ratio of nearly 6 kg of feed per kg of live weight or more than 12 kg of feed per kg of edible weight – while feed conversion ratios for milk is just 0.9 kg of feed/kg of the liquid. When adjusted for typical protein content (3.5% in milk, 18% average in the three meats) milk has a superior conversion ratio of about 25 kg of feed per kg of protein compared to 70 kg of feed per kg of protein for the average of the three meats.

In societies with moderate to high consumption of dairy products it would not be realistic to assume that their higher intake could displace more than 15% of meat protein by dairy protein, but if such an increased consumption were divided among whole and low-fat milk, yogurt, creams, cheeses and iced products it would be easily accommodated, being an equivalent of eating a standard portion of such foods four or five days a week rather than just three days a week. In countries with low to very low dairy consumption (China being the foremost example: its consumption could roughly triple before reaching the recent Japanese rate) higher dairy intakes could reduce the eventual meat demand by at least 20%. Increased egg consumption would also make a greater difference to protein supply in countries with low to moderate meat intakes: replacing just 10% of US meat protein with eggs would require the doubling of average annual intake to about 500 eggs, an unlikely shift. Realistic increases are thus no more than 5% in nations with high meat consumption but 10% in most low-income countries.

Meat substitutions by aquatic species would be most desirable of the three possible shifts but that could not be done by increasing marine catches: they have been stagnating for many years and returning them to responsible levels would require cutting recent landings by nearly 40%. This means that any gains should come from freshwater and marine aquaculture that can produce high-quality protein with superior feed conversion efficiencies when raising herbivorous and omnivorous species (as little as 1.1 units of feed per unit of gain). Carnivorous species require 20–40% of their diet either as fishmeal or as a combination of fishmeal and fish oil and such diets will yield a unit of gain for just 1–1.3 units of feed.

Fortunately this feeding does not have to reduce the overall supply of edible fish because species caught to produce fishmeal can be those without any market as food (menhaden, sand eel), those with limited market appeal (capelin, sprats, some mackerel and sardine species). And it is also incorrect to claim that leaving such fish for wild species would produce more protein because feed conversion efficiencies of wild fish feeding on the species used for fishmeal are lower than the feeding efficiencies of aquacultured salmonids or crustaceans. More importantly, plant substitutes (oils derived from soybeans and rapeseed) can replace part of fish oil, and breeding can further lower demand for fishmeals and oils in fish feed: as a result, global aquaculture has been expanding but the demand for fish-derived feeds has not risen.

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But there are obvious limits to fast growing aquaculture, and even tripling of its 2010 output during the next generation (realistic maximum) would displace less than 9% of 2010 global meat production but expanded freshwater aquaculture could bring that share closer to 10% and if it produced mostly herbivorous species its environmental impact could be limited. Diverting feeds into more efficient ways of producing animal protein could thus displace up to 25% of today's meat supply in affluent Western countries with high levels of meat consumption (15% by dairy products, 5% each by eggs and seafood) and up to 40% in Asian countries with moderate meat intake and traditional preference for freshwater fish (20% by dairy products and 10% each by eggs and seafood). In total, the combination of rational meat production and realistic meat displacements by other animal foodstuffs could produce at least 80% of high-quality protein that was supplied in 2010 by global meat output.

6. Future meat consumption

How does the annual output of some 200 Mt of meat (or animal protein equivalent of some 220 Mt) compare with forecast of future meat consumption FAO's latest long-range global forecast gives values accurate to 1 Mt: 374 Mt in 2030, 455 Mt in 2050, and 524 Mt in 2080 with increasing shares in lower-income countries. There is no way to produce more than 300 Mt/year by the means outlined for environmentally conservative ways that would eschew mass-scale feeding of grains and legumes. Nor is there any plausible path toward improving average feeding efficiencies by 35% in 25 years in order to produce more meat in 2030 without increasing the mass of feed grain (about 750 Mt) and legumes and other feedstuffs (about 200 Mt) that was used in 2010 to produce about 275 Mt of meat.

This leaves us with a clear conclusion that any substantial (more than 20%) increase of current meat production will require further intensification of existing feeding practices predicated on large-scale cultivation of feed crops on arable land and associated with many environmental burdens whose rate might be reduced by better management but as such improvements will not go beyond 20–25% gains the overall impacts would still worsen: by 2030 and even more so by 2050 our carnivory would exact an even higher environmental price than it does today.

But such an outcome is not foreordained: the world does not have to consume almost 400 Mt of meat in 2030. There is absolutely no need for higher meat supply in any affluent economy, and improved nutrition, better health and increased longevity in the rest of the world are not predicated on nearly doubling meat supply. Wealth of evidence confirms that adult per capita meat intakes on the order of 35–40 kg/year are compatible with good health and high longevity. Adjusting for lower consumption in childhood and old age (particularly among long-lived females) this translates to about 25–30 kg/capita, or 175–210 Mt of equally shared global production for the population of 7 billion people , the total that is identical or only slightly higher than the environment-sparing way of meat production outlined in this essay.

Obviously, I am not suggesting that global consumption inequalities could be eliminated in less than a generation in order to converge rapidly toward an egalitarian rational consumption mean: that would require roughly halving today‘s average per capita supply in affluent countries. What is both desirable and possible, and hence worth pursuing by all possible means, is a gradual convergence toward more evenly distributed per capita meat consumption, gradual elimination of the worst environmental transgressions involved in mass meat production (be it tropical deforestation or gargantuan concentrated animal feeding operations), continued quest for efficiency improvements in cropping and feeding, and gradual displacement of some meat consumption by environmentally less demanding animal foodstuffs.

Meat consumption does not present a unique challenge: it is helpful to see it as a part of much larger need for all forms of energy. Rising demand for meat or natural gas, corn or electricity cannot be met by a single kind of adjustment, most definitely not just by increasing production; in all cases it must be a combination of more efficient supply and moderated demand. A key mechanism aiding these pursuits would be gradual aligning of meat prices with the real cost of meat production. Meat, as well as most other foodstuffs and, indeed, all other forms of energy in modern societies, are more affordable not only because of continuing innovation and rising productivities but also because we have not been paying real prices for both food and fossil energies have been undervalued.

This trend is most obvious in the US where 40% of an average household‘s disposable income were spent on food in 1900 but now the share is less than 10% (and so is the share of income paid for fuels and electricity), even as the share of overall food spending going to farmers shrank to only about 5% in 2007, while the share going to restaurants is now about 15%. Consumers in the rich countries should be willing to pay more for food in order to lower the environmental impacts of its production, especially when that higher cost and the resulting lower consumption would also improve agriculture‘s long-term prospects and benefit the health of the affected population. Analogically, without higher prices and gradually reduced consumption there is no realistic possibility of limiting the combustion of fossil fuels and moderating the rate of global climate change.

7. Changing trends

So far, modern societies have shown little inclination to follow such a course but I think that during the coming decades, a combination of economic and environmental realities will hasten such rational changes, be it with fossil fuel or meat consumption. Unfortunately, those needed price adjustments may not be gradual: FAO food price index stayed fairly steady between 1990 and 2005, and then the post-2008 spike lifted it to more than double the 2002–2004 mean. Market studies show that higher prices in affluent countries would undoubtedly reduce meat consumption, but their effect on food security on low-income nations is much less clear. For decades, low international food prices were seen as a major reason for continuing insecurity of their food supply (making it impossible for small-scale farmers to compete), but that conclusion was swiftly reversed with the post 2007 rapid rise of commodity prices that came to be seen as a major factor pushing people into hunger and poverty.

In any case, it is most unlikely that food prices in populous modernizing nations will decline to levels now prevailing in the West: most notably, China‘s food bill is still 25% of household disposable income, and given the country's enormous environmental problems and rising cost of feed imports, it is certain that it will not be halved yet again by the 2030 s as it was during the past generation. And food production and supply in India, Indonesia, Pakistan, Nigeria or Ethiopia are far behind China's achievements, and they will put even greater limits on the eventual rise in meat demand.

Unpredictable events, or events whose eventual occurrence may be anticipated but whose timing is beyond our ken, will eventually lead to some relatively rapid changes. Examples of such events are not in short supply: chronic drought in the western half of the US, in California now so serious that most of the state is classified to be beyond severe and extreme categories; chronic

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water shortages and rapidly declining availability of high-quality farmland in China, a country too large to be fed largely by grain imports as is the case with Japan or South Korea; worldwide spread of antibiotic resistant bacteria, a phenomenon caused primarily by overuse of antibacterial drugs in meat production; and an uncertainty about the future course of global warming: we may have another decade of relatively slow temperature increases, or we may return to, or even beyond, the fast temperature gains of the 1980s.

Some changes are already evident. Most Western nations and Japan have already seen saturations of per capita meat consumption: consumption growth curves have entered the last, plateauing, stage, and aging of Western population and, in many cases, their absolute decline appear irreversible. By 2050, roughly two out of five Japanese, Spaniards and Germans will be above 60 years of age; even in China that share will be one-third. Judging by the recent German, Japanese (and even urban Chinese) experiences, aging of populations will not be accompanied by rising meat intakes. Moreover, many smaller European countries as well as Germany, Japan and Russia will have millions (even tens of millions) fewer people than they have today. And in the US, where beef consumption has been already in long-term decline, extraordinarily high rates of overweight and obesity, accompanied by enormous waste of food, offer a perfect combination of reasons for greatly reduced meat consumption. Most low-income countries are still at points along the rapidly ascending phase of their consumption growth curves, but some are already approaching the upper bend.

Producing 30% or 50% more meat simply by the extension of current practices is possible but it is neither rational nor sustainable. As always, specifics are impossible to predict but I think that during the next two to four decades, the odds are more than even that many rational adjustments needed to moderate livestock's environmental impact (changes ranging from higher meat prices and reduced meat intakes to measures moderating environmental burdens) will take place – if not by design, then by the force of changing circumstances.

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