A Fair Share: Doing the Math on Individual Consumption and Global Warming

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Chapter 18

Introduction to food and agricultural emissions

In this part of the book, I review the GHG emissions embedded in food consumption, and determine what aspects of food consumption contribute most to emissions, with my primary focus on agricultural production systems, and not the downstream energy involved in the larger food system, such as that devoted towards refrigeration and cooking. Overall, the indirect emissions associated with diet likely sum to at least 3.0 $MgCO_2e$ per capita, with 4.0–4.5 $MgCO_2e$ a more likely figure (in my accounting), and thus food is responsible for around 15–20% of the average American's total carbon footprint. Via a conservative accounting, by simply avoiding beef and cutting most (or all) food waste, one can decrease their food-related emissions by 40%, and avoid 1.25–2 $MgCO_2e$ in absolute terms.

The production and consumption of animal products, i.e. meat, dairy, and eggs, but especially beef, is the dominant contributor to the negative environmental profile of modern agriculture. The carbon impact manifests mainly through the upstream emissions embodied in feed production (via fertilizer production and application, fuel use, irrigation, etc.), the end towards which a large fraction of crops in the US are actually grown, methane emissions from ruminants (cows, goats, sheep), nitrogen oxide (N_2O) and methane emissions from manure management, and carbon lost from agricultural land-use change. Agriculture is also, by far, the largest use of land in both the US and globally (about 60% of the continental US is devoted either to crops or grazing), and is the principle cause of deforestation and habitat destruction worldwide; a disproportionate amount of this land is devoted either directly or indirectly to livestock. Thus, in addition to their carbon emissions, livestock are the dominant cause of land-use change and habitat loss worldwide.

Beef is uniquely destructive, varying qualitatively in its carbon and land-use impact relative to all other animal products (this holds true for 100% grass-fed, or "grass-finished" beef too, which probably has a *higher* global warming impact than conventional beef), while eggs and poultry are probably the least damaging, with pork also relatively low-impact. Depending upon how we perform our comparisons (i.e. energy- vs. protein-based) dairy is either similar or somewhat worse than monogastric products, i.e. poultry, eggs, and pork, and so beef stands alone as the top dietary environmental offender in the US. Seafood is a small component of US diets, and is generally similar to poultry or pork in terms of per-unit GHG emissions, although deep-water fish harvested via seabed trawling may have a carbon impact more similar to beef (and are highly damaging to the fragile seafloor ecosystem), and some shrimp sources from Southeast Asia are associated with truly astronomical emissions due to the destruction of mangrove forests for shrimp ponds.

It should be noted that different animal production systems also entail issues of animal welfare that do not closely correlate with their carbon and land-use impacts: beef cattle may be treated most humanely on average, typically living half- to two-thirds their lives in unconfined pasture systems with calves staying with their mothers until weaning, and only moving to feedlots, which are certainly less confining than battery egg cages or gestation crates, in the last part of life. While raising cattle for dairy is more efficient overall and less emissions-intensive, calves are removed from their mothers within days, males enter directly into the beef system, most conventional dairies are based on confinement systems, the average lifespan of a lactating dairy cow is actually less than that of a mother beef cow, and the ultimate fate of all dairy cattle is slaughter for beef anyway. Highly confined systems are the norm for most pork, poultry, and egg production systems, but these systems (especially poultry and eggs) also are very efficient, and generate the fewest emissions per unit of protein produced. However, the "carbon premium" for free-range pork and poultry/egg systems is minimal, and so more humane alternatives are entirely feasible at a large scale, especially if overall consumption is concomitantly decreased.

Waste is remarkably prevalent throughout food systems worldwide, and embodies vast amounts of avoidable emissions: between 30 and 50% of all produced food is ultimately wasted, and in developed countries the greater portion of this waste occurs at the post-consumer level, i.e. following purchase at the supermarket, etc.

Transportation-related emissions are actually a more minor component of dietary carbon footprints, and while buying locally may have other, more difficult to quantify advantages, the issue of "food miles," while not entirely trivial, is a more secondary concern. In addition, about three-fourths of food-related transportation occurs upstream of the farm gate (transport of animal feed, etc.), and far more transport miles overall are embodied in animal products, especially, again, beef, than other plant-based foods. Thus, even "local" beef likely embodies more transportation-related emissions than even the most exotic plant faire. It must also be emphasized that demanding local production in many areas that are intrinsically poorly suited to arable crops would require destroying vast tracts of native ecosystems for much lower yields than might be obtained elsewhere.

Organic production, which eschews synthetic fertilizer and pesticides, avoids emissions and other externalities from these sources, but is also less productive, requiring more land and other inputs for the same output, and thus yields per-unit carbon emissions similar to conventional foodstuffs. Additionally, because manure and animal by-products such as bone and blood meal, which may (and usually do) come from conventional animal systems, are the primary fertilizers in organic systems, organic production is largely dependent upon conventional agriculture as an input source, and it is highly unlikely that organic, as a system, is scalable (and less than <1% of cropland is currently under organic management in the US, with this share even smaller globally). The most environmentally beneficial aspect of organic production is likely the avoidance of synthetic pesticides, which are associated with multiple serious ecological harms, including food web disruptions, grassland bird declines, and large-scale pollinator declines. However, even in conventional systems, around 50% of pesticide use is likely avoidable without yield reductions, and the sparing use of pesticides may help to reduce agricultural land requirements.

It follows from all this that reducing meat and dairy, *especially beef*, consumption and food waste are by far the two most important things that consumers can do. The majority of synthetic fertilizer, pesticide, freshwater, fuel, and agricultural land go towards these two ends, and thus dietary shift away from these two categories (meat and waste) is far more impactful than a dietary shift to, say, a local or organic diet otherwise equivalent to that of a typical American. To reiterate once more, *dietary shift away from beef primarily (and all other animal products including dairy, secondarily)* and *food waste reduction* are the most effective strategies for reducing the climate impacts of diet. One need not follow a strictly vegetarian diet, and indeed, dairy is slightly worse overall in terms of carbon and land-use impact than poultry, and the emphasis should be on rational harm reduction over abstention. Organic or other variations on non-conventional food may be preferable in selected cases, but there is not an obvious systemic advantage, and indeed, a broad shift to organic methods, without other dietary shifts, would likely require more land and widespread habitat destruction. Any environmental benefit to local food is context-dependent, and avoiding excessive "food-miles" is generally of minor importance.

The final obviously destructive component of modern agriculture is the production of food crops for fuel, most notably corn ethanol. This, like most other bioenergy and biofuels, is, in my view, an environmental farce. Corn ethanol is predominant in the US, where nearly half the annual corn crop now goes toward this end, which is futile for several reasons. First, the energy return on investment is abysmally low for corn ethanol, hovering around unity, i.e. it takes exactly as much energy to produce ethanol as one gets from it. Second, while optimistic analysis by the EPA projects lifecycle carbon emissions about 20% lower for ethanol than gasoline, proper accounting of nitrogen fertilizer-related emissions and land-use change may imply a carbon footprint as much twice as bad. Third, even under the most optimistic analysis, corn ethanol can only reduce US passenger car emissions by about 1.5%, equivalent to increasing the fleet-average MPG from 21.6 to 21.9 MPG (see Section 22.3). Thus, animal products but mainly beef, waste, and biofuel form a trifecta of excess and avoidable climate and broad environmental harm attributable to the agricultural system. The former two are directly in the hands of the consumer.

18.1 Overall impact

Multiple reviews have estimated that globally, food systems generate on the order of 15–30% of all anthropogenic carbon emissions, including indirect emissions from land-use changes. A recent comprehensive review by Vermeulen and colleagues [316], gave an emissions estimate range of 9.8–16.9 $GtCO_2e$ for 2008, or 19–29% of the global total, with the vast majority, 80–86%, attributable to on-farm agricultural production (including land-use changes). Note however that, in developed countries such as the US, post-farm energy and emissions make up a relatively greater share of food system emissions [317].

The major points in the overall food system include [316] (1) production of *inputs* (fertilizers, seeds, pesticides), (2) agricultural production (crops, livestock, and wild food production, e.g. fisheries), (3) processing, packaging, transportation, and distribution, and (4) consumer-level management and waste disposal. Note that waste occurs at all stages of this system, and while waste disposal is a relatively minor *direct* source of emissions (via landfill methane from anaerobic food breakdown), 30–50% of all food is ultimately wasted, representing a vast quantity of embodied energy, land, water, and carbon. In the subsequent section, I derive an order-of-magnitude estimate for US food system CO_2e, and then give this estimate in disaggregated form.

18.1.1 Top-down estimate for US agricultural and food system emissions

- Major aggregated emissions sources in the US food system include methane from cattle herds (1.0–2.5 $MgCO_2e$/capita); synthetic nitrogen fertilizer production and downstream N_2O emissions from soils and manure (perhaps 1.0 $MgCO_2e$/capita); other fertilizer production, pesticide production, on-farm energy use, irrigation, transportation, and food waste landfilling (together around 1.0 $MgCO_2e$/capita); ecosystem carbon loss from conversion to agriculture (0.5–1.5 $MgCO_2e$/capita depending upon accounting), and finally, downstream food processing and handling, not counting residential refrigeration, cooking, etc. (0.75–1.75 $MgCO_2e$/capita).
- From a top-down accounting, total US food system emissions likely sum to about 1.25–2 billion $MgCO_2e$ (about 4–6 $MgCO_2e$/capita), with around 75–80% of emissions upstream of the farm gate.

In this section I derive an order of magnitude top-down emissions estimate for the entire US agricultural system, which is likely to be in the 3–4 $MgCO_2e$/capita range when not counting food processing, packaging, retailing, and commercial preparation downstream of the farm gate, and more likely 3.75–5.5 $MgCO_2e$/capita if these activities are included. In the subsequent chapters, I provide much more detailed derivations of the basic numbers presented here.

For cropping systems, we have emissions from (1) fertilizer, mainly nitrogen (N) fertilizer (at both the production and application phases), (2) pesticides, (3) irrigation water, (4) on-farm fuel and electricity use, (5) land-use change emissions, and (6) transportation from the farm gate. Downstream of the farm gate, corn, soy, and forage are fed to animals, where a fraction of feed carbon is converted to methane via enteric fermentation, another fraction becomes methane via manure management, and some manure nitrogen also evolves to N_2O. Enteric fermentation, primarily from beef herds, is likely the single largest source of agricultural GHG emissions. Grazing and pasture/rangeland management also affect ecosystem carbon stores, often, but not uniformly, negatively.

First let us consider methane due to livestock. Recent top-down, satellite-based measurements of US methane emissions by Turner and colleagues [96] estimated annual livestock-attributable CH_4 at 12.6–17.0 million tonnes, or 29–44% of US methane (over the 2009–2011 period). This translates into 428.4–578.0 million $MgCO_2e$ (under a non-fossil methane GWP of 34), or, using the 2011 population, 1.37–1.85 $MgCO_2e$/capita. Similarly, a top-down work by Miller et al. [25] gave 17.0±6.7 $TgCH_4$ due to ruminants and manure, or up to 2.5 $MgCO_2e$/capita, while Wecht et al. [320] gave 12.2±1.3 $TgCH_4$ for the year 2004 (i.e. 1.41±0.15 $MgCO_2e$/capita). These figures significantly exceed the EPA inventory estimate of 9.381 million $MgCH_4$ from livestock (for 2013), which equates to "just" 1.0 $MgCO_2e$/capita. Note that in this inventory, the EPA attributes about 70% to ruminant enteric fermentation (with the remainder from manure), and of this, 71% to beef cattle. The sum of the evidence therefore suggests *at least* 1–1.5 $MgCO_2e$/capita attributable to CH_4 from livestock. Note that US rice cultivation (not including international imports), may have added another relatively scant 11.3 $MgCO_2e$ of methane (based on EPA inventory).

Fertilizer, mainly nitrogen (N) produced via the industrial Haber-Bosch process, leads to N_2O emissions both from fertilized fields and from downstream transformations, e.g. through animal manure. Supposing about 5 $kgCO_2e$/kg N for fertilizer production, and 3–5% ultimately evolving to N_2O [348] (see Section 20.1.3), then the 11.648 million Mg of synthetic N used in US agriculture (in 2011), would yield on the order of 222–331 million $MgCO_2e$ of N_2O.

Nitrous oxide is also released via mineralization of N during the decomposition of soil organic matter, and via free-living bacteria in agricultural soils [10], and the EPA inventory estimated

263.7 million $MgCO_2e$ of direct and indirect N_2O emissions from agricultural soils in 2013 (including grasslands), with only 61 million $MgCO_2e$ directly attributed to synthetic fertilizer (the largest contributor was actually mineralization and asymbiotic N fixation, at 119.2 million $MgCO_2e$). Manure management added just 17.3 million $MgCO_2e$, for a total of 280 million $MgCO_2e$. It is thus unclear exactly how much N_2O is attributable to US agriculture, but it is probably on the order of 1 $MgCO_2e$/capita, and possibly more.

Other fertilizer production, i.e. phosphorus and potassium (potash), together adds a fairly trivial 6 million $MgCO_2e$, and pesticide production may add around 7.5 million $MgCO_2e$. On-farm energy use, excluding pumping energy for irrigation, most likely generates on the order of 100 million $MgCO_2e$ annually, while irrigation may add something like another 50 million $MgCO_2e$. Transportation throughout the food system (including transportation upstream of the farm gate) may generate 80–100 million $MgCO_2e$. These numbers are derived in Chapter 20. Landfilled food waste could add another 30–50 million $MgCO_2e$ through anaerobic decomposition to methane, as discussed in Chapter 24. Summing all these factors gives around 275–315 million $MgCO_2e$, or about 0.85–1 $MgCO_2e$/capita.

Bringing pristine land under cultivation tends to release large amounts of carbon, but how and whether to include this as a dietary carbon emission is uncertain, as most historical prairies fell to the plow long ago. As discussed in Section 20.3, long-term prairie soil organic carbon (SOC) losses are about 2–3 $MgCO_2e$/hectare[1]/yr after conversion to cropland, suggesting emissions equivalent to 330–495 million $MgCO_2e$/yr. Since taking cropland out of production restores soil carbon, but at a lower rate, 180 million $MgCO_2e$/yr is probably a reasonable minimum SOC penalty to US agriculture, not counting the uncertain effects of grazing on pasture and rangeland.

Summing up all production emissions suggests slightly over 1 billion $MgCO_2e$/year due to US agricultural production, but possibly >1.5 billion $MgCO_2e$ at the extreme upper end, especially if we use a high estimate for land-use change emissions. In other words, per capita agricultural emissions are likely in the 3–4.75 $MgCO_2e$ range.

Considering the extended food system of food processing and purveyance downstream of the farm gate, but upstream of the consumer, is a major end-use of energy in American society. A USDA study [318] concluded that food processing consumed 0.79 trillion kWh of *primary* energy in 2002, while packaging and the wholesale, retail, and food services together used 1.4 trillion kWh of primary. Cuellar et al. [319], on the other hand, gave just under 1 trillion kWh of primary energy for all such processes. In either case, supposing an emissions factor of about 0.2 $kgCO_2e$/kWh for primary energy, these numbers translate into anywhere from about 200 to 450 million $MgCO_2e$ per year overall, and thus, downstream of the farm gate, an additional 0.7–1.75 $MgCO_2e$/capita are added by various food handling and processing processes, aside from residential energy use. We then arrive at a grand total of 3.6–6.5 $MgCO_2e$/capita as a plausible range for total upstream US food system emissions, with 4.5–5.0 $MgCO_2e$/capita perhaps a reasonable best guess. This estimate is slightly higher than that of most existing bottom-up lifecycle analyses, largely due to the inclusion of land-use changes, downstream food processing, and higher ruminant methane emissions. Figure 18.1 shows low, "best," and high estimates of pre-consumer food system emissions by mechanism.

[1]A hectare (Ha) is 10,000 m^2, and equal to 2.47 acres; this is the primary unit for land area used in this book.

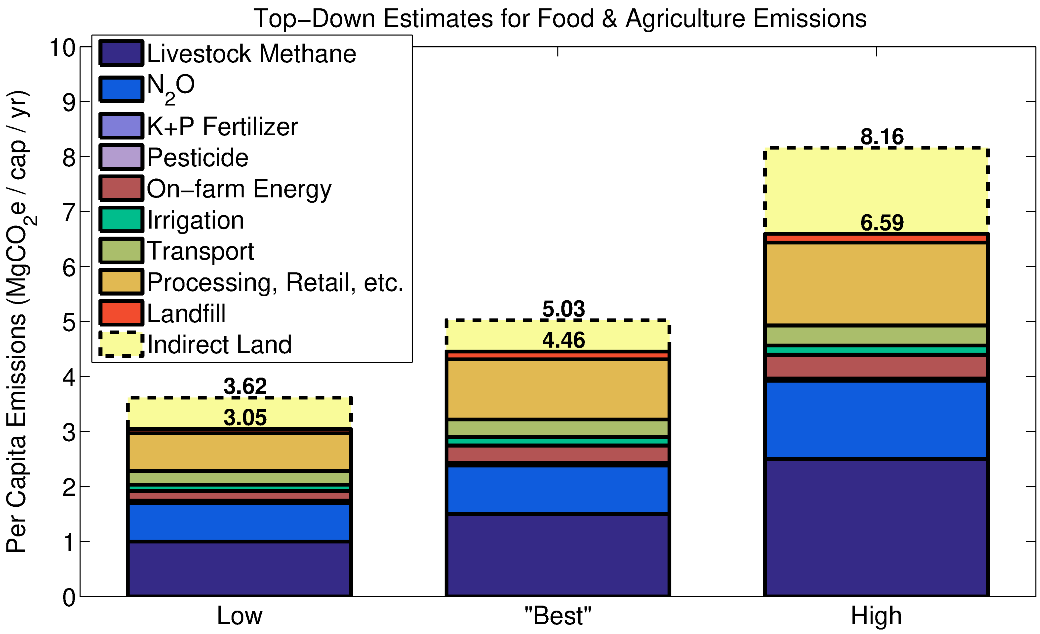

Figure 18.1: Low, best, and high top-down estimates for the US food and agriculture system (not including consumer-level energy use related to cooking, refrigeration, washing, etc.), disaggregated by major mechanism, and given in per-capita terms. Ruminant methane includes enteric fermentation from ruminants and manure emissions from all livestock; N_2O is the sum of N_2O from new reactive nitrogen (mainly synthetic fertilizer), agricultural soils, and manure. Note that phosphorus (P), potassium (K), and pesticide production emissions are too minor to be clearly seen. Indirect land use emissions related to carbon loss from agricultural soils is less certain, and the numbers above each bar give per-capita emissions with and without its inclusion.

18.2 Bottom-up emissions factors for major foods, and total bottom-up emissions

Overall, as a general guideline, bottom-up estimates suggest *production* emissions factors (by weight) are around 0.25–2 kgCO_2e/kg for various plant products, including high-protein legumes, grains, tubers such as potatoes, fruits and vegetables, etc. (see, e.g. [321]), around 2.5–7.5 kgCO_2e/kg for monogastric animal products, i.e. eggs, poultry meat, and pork, as well as much seafood, and on the order of 1.5–2.0 kgCO_2e/kg milk but around 10–15 kgCO_2e/kg for solid cheeses. Beef is qualitatively worse, with an EF on the order of 30–50 kgCO_2e/kg. These factors are derived in detail in the following chapters.

In other words, as one moves from plants to eggs, poultry, pork, fish, and dairy, production emissions factors increase by a factor of 5–10. Moving from this latter category of moderate-impact animal foods to beef (and other ruminant meat, such as lamb and goat), emissions again increase five to tenfold. Thus, per unit weight, CO_2e impact varies across two orders of magnitude, from plant to cow. Once post-farm processing, packaging, and distribution are accounted for, we likely add 0.75–2.5 kgCO_2e/kg for any given food, depending upon its post-farm gate lifecycle.

Note that these bottom-up estimates, when applied to retail-level food availability, suggest a total diet carbon footprint on the order of 2.25–3.5 MgCO_2e/capita/year, appreciably lower than the top-down range derived above. Part of the gap is probably explained by higher ruminant methane emissions in top-down studies: bottom-up analyses are more consistent with just about 750 million MgCO_2e from beef and dairy enteric fermentation, which is probably too low by at least 25% and quite possibly by more than a factor of two. Crudely correcting adds around 5–10 kgCO_2e/kg beef and 0.5–0.67 kgCO_2e/kg milk, and bumps our overall bottom-up estimate range to about 2.6–3.85 MgCO_2e/capita/yr.

Additionally, land carbon losses are, in the main, disregarded in bottom-up estimates. Taking a reasonable minimum total, 180 million MgCO_2e (see Section 20.3), and our bottom-up estimate corrects to about 3.15–4.4 MgCO_2e/capita/yr, with at least 0.25 kgCO_2e/kg added to plant products (derived from a crude division of about 750 million tonnes of primary productivity across 180 million MgCO_2e), perhaps 1 kgCO_2e/kg added to monogastric products, and >3 kgCO_2e/kg added to beef (assuming feed conversion factors in [322], and that 67% of beef cattle dry matter intake is pasture, based on [439]).

Finally, adding in transportation emissions on the order of 100 million MgCO_2e, and we should add at least 0.133 kgCO_2e/kg to plant products, about 0.5 kgCO_2e/kg to monogastric products, and 1.75 kgCO_2e/kg to beef (also based on 750 million tonnes of primary productivity and feed conversion efficiencies as above), and our final bottom-up emissions estimate corrects to 3.45–4.7 MgCO_2e/capita/year, mostly within the lower half of our top-down estimate above, and a reasonable bottom-up midpoint estimate might be a somewhat lower 4.0 MgCO_2e/capita/year, or 3.5 MgCO_2e/capita/year if we disregard indirect land use. Note now, that even with production emissions on the order of 0.5 kgCO_2e/kg, plant-based products may be expected to have a net impact anywhere from 1 to 3.5 kgCO_2e/kg, with half or more of the impact, on average, post-farm. This is still anywhere from 2–10 times better than typical monogastric and dairy products, and 10–50 times better than beef. Emission factors for animal products, on the other hand, are still uniformly dominated by on-farm production.

Estimated food system emissions, using per-unit emissions factors as above and with adjustments for post-farm processing, packaging, retail, transport and indirect soil carbon losses are given in Figure 18.2; results are given for representative low, "best," and high emissions factors, both with and without indirect land use losses. Reasonably consistent with other lifecycle analyses (e.g. [321]), beef alone is responsible for one-third or more of all food system emissions,

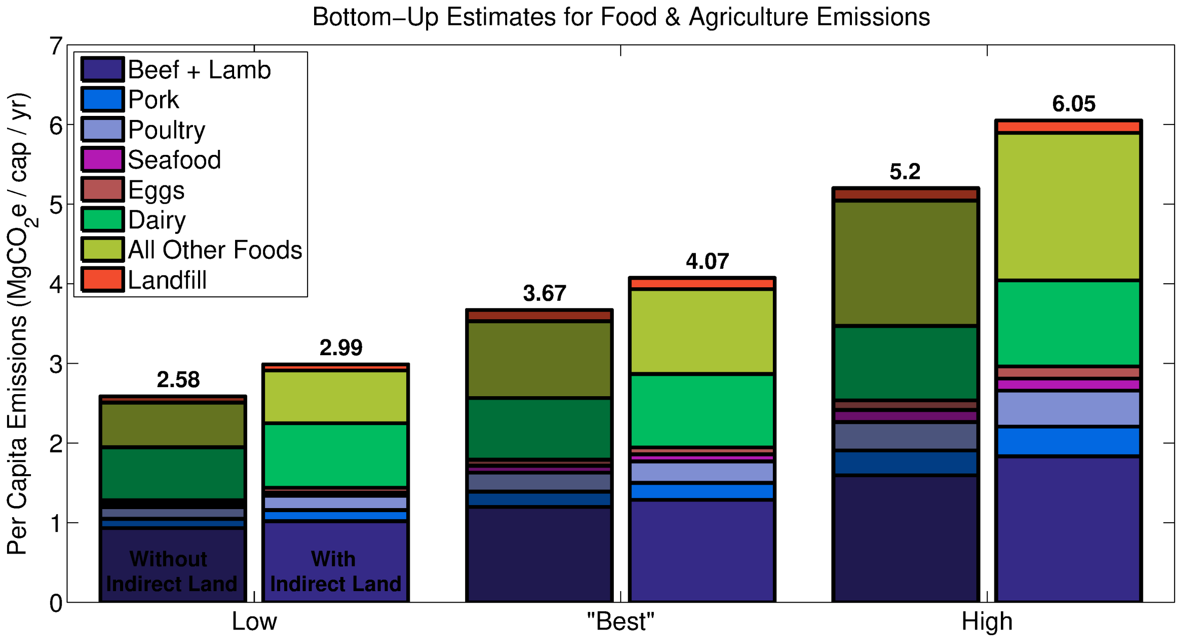

Figure 18.2: Low, best, and high bottom-up estimates for the US food and agriculture system CO_2e emissions, on a per-capita basis (not including consumer-level energy use), either with or without approximate corrections for indirect soil carbon losses (left and right bars for each estimate, respectively), using food-specific emissions factors (including transport and post-farm processing, retail, etc.) for major food categories (and using USDA LAFA database for major food retail availability). Comparing to Figure 18.1, even with some adjustments as discussed in the text, a bottom-up analysis gives a dietary carbon footprint about 20% lower than a top-down approach.

while dairy contributes on the order of 20–25%, other meat and eggs together yield 15–18%, and all other foods taken together account for just 25% of food-related CO_2e; landfilling of food waste and the resulting methane from anaerobic breakdown gives the final 3–4%.

18.3 Carbon footprint for typical dietary patterns

Several lifecycle analyses have addressed the carbon footprint of typical whole diet patterns, the most common being typical omnivorous, lacto-ovo vegetarian, and vegan, but we may also compare lower and higher meat diets, pescetarianism, etc. Unsurprisingly, there is generally an association between less dietary meat and dairy and lower emissions.

18.3.1 Some existing whole-diet studies

Multiple studies have attempted to quantify the GHG emissions associated with typical diets. The majority of estimates are specific to the UK and several other western European countries, although several US-specific estimates exist. There is significant uncertainty in the precise EFs for various food types, post farm-gate emissions are often unaccounted for in these works, food wastage is variably considered, and the effects of upstream land use are also generally disregarded, so we must be cautious in drawing conclusions concerning the overall CF of a typical western diet, but several findings are robust, mainly that waste and (red) meat are large contributors to the diet CF, with lower meat diets less impactful, and that vegan diets generally hold a small advantage over vegetarian diets (given the relatively high overall and per-unit impacts of dairy products).

In brief, to estimate average dietary CF, the commodity components of a typical diet are estimated from national inventories of consumption (e.g. LAFA as used by Heller and Keoleian [321]) or from diet questionnaires, e.g. [323], and then matched to CO_2e emissions factor estimates abstracted from the larger literature. In addition to the omissions noted above, the use of diet questionnaires almost certainly leads to underestimation of dietary CF, as they are well-known to systematically underreport energy intake, do not account for food that is purchased and not consumed, and further ignore food waste upstream of the consumer [324]. Given that roughly 30% of food is wasted at the consumer level, we may safely increase estimates derived from diet questionnaires by about 40%. Furthermore, in some studies consumption is normalized to a 2,000 kcal diet, a practice that clearly reduces estimated emissions substantially, and we may safely double the estimated impact from such studies (about 4,000 kcals per capita reach the retail stage in the US).

Turning to results, Berners-Lee et al. [324], using a combination of FAO data on per capita calorie availability, combined with survey results on actual diets, estimated the average UK diet embodies 2.7 MgCO_2e/year (scaling from 3,548 kcal/capita in the UK to about 4,000 kcal/capita in the US suggests 3.0 MgCO_2e/yr, likely an underestimate), and moreover concluded that vegetarian and vegan diets might, on average, offset 22% and 26% of this total, respectively, although they suggest this offset may be higher if land use changes are accounted for.

Scarborough et al. [325] also recently estimated dietary GHG emissions for UK diets with different levels of meat consumption, using data from a large survey on dietary habits to inform diet habits. Since diets are likely to vary pervasively depending upon the degree of meat consumption, this methodology may yield results that correspond better to the GHG impact of broad classes of diets, as actually practiced. In short, yearly emissions for normalized 2,000 kcal diets were 2.65, 2.16, 1.70, 1.41, and 1.07 MgCO_2e/year for high-meat, average-meat, low-meat, vegetarian, and vegan diets, respectively. Note that we should roughly double the numbers to reflect the actual 4,000 kcal US diet for more accurate absolute emissions estimates. It is very notable that a low-meat diet reduced CO_2e by 36% and 21% relative to high and average-meat diets, respectively, and thus abstinence is not an absolute requirement for a relatively low-carbon diet. It is also notable that meat consumption was actually relatively low in this study, with "high-meat" diet defined as >100 g/day, yet average per-capita meat consumption in the US is about 240 g/day. Along similar lines, Heller and Keoleian [321] found beef alone to account for 36% of dietary CO_2e, in the US.

It should finally be noted that vegetarian and vegan diets tend to be slightly lower in calories than typical omnivorous diets [325], and incorporating this improves the relative benefit of meat-free diets by perhaps 3–5%.

18.3.2 Some general conclusions

From the prior sections, it should be apparent that a diet that simply cuts out beef, without any other change, will avoid 30–40% of diet-associated CO_2e. If one were to additionally reduce other meat and dairy by, say one-third, with protein replaced by legumes or other high-protein plant foods, then overall diet CF would fall to just 50–60% of the typical diets. The bottom line is that, although vegetarian and vegan diets are fine choices, a more nuanced harm-reduction approach that gives beef avoidance top billing can be just as or even more effective than vegetarianism, and likely far easier to implement in practice.

18.4 Carbon footprint of food waste

Food loss and waste consumes vast quantities of resources. Note that we distinguish between *loss*, which includes all types of loss, including cooking losses, shrinkage, spoilage, etc., and *waste*, which refers more strictly to otherwise edible food that is discarded. USDA researchers have estimated food loss at the retail and consumer levels to amount to 60.45 million tonnes per year, or 31% of the entire (195.45 million tonne) US retail food supply [326]. The methodology is based on the LAFA database, and excludes inedible commodity portions, e.g. bones and skins. While the method cannot distinguish between loss and waste, given the vast disparity in consumer level wastage between developed and developing nations as estimated by the FAO [327], these losses are probably overwhelmingly waste *per se*.

Heller and Keoleian [321] recently applied LCA to study the CF of food waste at the retail/consumer level, and estimated that, by weight, 31% of the US food supply is lost at the retail/consumer level, with two-thirds of this waste occurring at the consumer level. They further estimated the GHG emissions of a typical diet to be 5.0 kgCO_2e/day, with 1.4 kgCO_2e due to wastage, i.e. 28% of the total CF. Only a very small portion of waste is inedible, e.g. fruit peels, egg shells, with the majority simply food that goes bad in storage. Furthermore, a 2011 FAO report [327] estimated that while European and North American consumers directly waste 95–115 kg of food per year on a per capita basis, consumers in sub-Saharan Africa and South and Southeast Asia waste only 6–11 kg/year. These facts together suggest that a 90% reduction in typical consumer-level food waste is achievable via behavioral change alone.

Under my estimates of dietary CF, as derived above, yearly upstream GHG emissions attributable to waste are likely around 1–1.5 MgCO_2e per capita, assuming about 30% of diet-related emissions are due to waste. Including the GHG impact of landfilling food scraps (due to anaerobic decomposition yielding methane, as discussed in Chapter 24) increases waste-related emissions by 10% or so, at perhaps 100–200 kgCO_2e/capita.

18.5 Eating locally: food miles and land suitability

The idea of reducing "food miles" and thus emissions related to burning fossil fuels for transport has been widely promoted as the environmental basis for eating locally. There are any number of calculations that give staggering miles counts for a meal, with total meal miles numbering in the 10,000s. As a general caveat, there is no general agreement on what counts as local, although the "100-mile diet" is a popular rule-of-thumb.

An economic input-output lifecycle analysis by Weber and Matthews [328] found "food miles," i.e. transportation from producer to retail, to account for only about 4.4% of food system emissions, or 0.36 MgCO_2e/household/yr, translating into about 0.144 MgCO_2e/capita/yr. Transportation in general was estimated at about 11% of US agricultural emissions, and thus about two-thirds of transportation emissions in the food system actually involve upstream activities, such as feed and fertilizer transport, and not final delivery to retail. Of note, total embodied miles in the supply chain and transportation-related emissions were, unsurprisingly, highest for red meat, with the supply chain entailing a total of 12,680 miles (of which just 9%, about 1,200 miles, was final delivery to retail), thrice the average of 4,200 miles (with only 1,020 of this being final delivery).

Obviously, eating "locally" does not eliminate all food miles, and we can do some simple back-of-the-envelope calculations to compare local farmers' market products to the commercial food chain. Suppose a (gasoline-powered) pickup truck transports 1 tonne of produce 20–100 miles from a farm, and gets 17.2 MPG. Then (including both legs of the trip) we would have 25.92–129.60 kgCO_2e/tonne food and an emissions factor of 0.648 kgCO_2e/tonne-mile.

Average final delivery in the food system is 1,020 miles, Weber and Matthews used 0.2897 $kgCO_2e$/tonne-mile for truck freight, which would give 295.5 $kgCO_2e$/tonne produce. Thus, eating locally would indeed save 56–92% of the food-mile emissions, in this case. Note that food-mile emissions could plausibly be worse for the farmers' market: a 40-mile round-trip would yield equivalent food-mile emissions if 87.7 kg (193.3 lbs) of produce were sold, while a 200-mile round-trip would need to move 438.6 kg (966.9 lbs) of produce to break even.

Also noteworthy, a more rigorous analysis by Cleveland and colleagues [329] concluded that if all produce consumed in Santa Barbara County was grown in the county, then food-related greenhouse gas emissions would fall by a scant $<1\%$.

Commonly neglected in popular discourse is the fact that certain areas are intrinsically better suited to agriculture, and that agricultural extensification into many areas, such as tropical forests, carries very high costs in carbon, biodiversity, and other ecosystem services. For example, a model by Johnson et al. [330] found that, globally, there are a few geographic hot spots where selective extensification preserves far more ecosystem carbon than a business as usual scenario that expands production in all areas proportionally. That is, by expanding farming into a few concentrated regions where ecosystem carbons losses are comparatively low and productivity high, overall environmental impact is minimized, despite the fact that such expansion is necessarily non-local to most of the populace. In the US, carbon stores were maximized by expanding agriculture primarily at the edges of the US corn belt, while crop expansion into much of the American West, and especially Southwest, carried a very high carbon cost and was best avoided [330].

Overall then, there may be good reasons to eat locally, but reducing food-miles may not be a primary one, as it is only a marginal contributor to total emissions, and depending upon the product, certain local foods (mainly meats) may embody far more supply chain miles than non-local alternatives. Agricultural production practices, the particular foods being produced, and the intrinsic suitability of the land to farming are of far greater importance to the agricultural footprint. Therefore, consuming a local product may or may not be more environmentally friendly than a more globalized alternative.