Supplementary Information for

How to Prioritize Voluntary Dietary Modification

Calculating I_{GHG} for greenhouse gas emissions. Recent years' mean U.S. diet results in emissions of about [1, 2] 985 million metric ton of CO_{2eq} y^{-1}, some 15% of the *total* national emissions [3]. Second, direct emissions from agricultural production (as distinct from the full food supply chain reported above) account for 10% of the same national total [3]. Therefore, $\sigma_{GHG} \approx 0.1 - 0.15$. Turning next to ρ_{GHG}, the expected range various viable alternatives span, we have shown [4] that emissions per beef kcal are 10-20 times larger than those of plant staples (such as rice or wheat), and about 10 times larger than those of poultry or pork. Examining instead emissions per g protein [4, 5] reveals a tighter range inside 10-20. With the above,

$$I_{GHG} \sim (0.1 \text{ to } 0.15) \times (10 \text{ to } 20) \sim (1 \text{ to } 3).$$

Calculating I_{eut} for water pollution by eutrophication. To estimate σ_{eut} indirectly, we turn to the well-studied northern Gulf of Mexico Dead Zone, at the mouth of the largest and most quintessentially agricultural watershed in the U.S., the Mississippi. Of the total reactive nitrogen load that fuels that Dead Zone, 67% is of agricultural origins [6]. Earlier analysis [6] of watersheds throughout the U.S. reveal that agricultural sources contribute more than 70% of the N and P loads. About 65-70% of the scope of the eutrophication problem is thus due to agriculture, i.e., $\sigma_{GHG} \approx 0.65 - 0.7$. Turning next to ρ_{eut}, we note [4] that the reactive nitrogen needs per beef kcal are 10-20 times larger than those of rice or wheat, and about 8 times larger than those of dairy or eggs. Per g protein results [4] are also consistent with this ρ_{eut} range. Combining these values,

$$I_{eut} \sim (0.65 \text{ to } 0.7) \times (8 \text{ to } 20) \sim (5 \text{ to } 14).$$

Calculating I_{wat} for water use. Agriculture accounts for 70% of global freshwater use[7]. For this burden, we must distinguish the two dichotomous regimes—plentiful water whose availability constrain agricultural productivity minimally vs. water shortage that strongly limits such productivity—most agricultural lands exhibit. In the U.S., this means the "eastern" and "western" regimes, crudely separated by ≈95°W. In the eastern regime, precipitation minus evaporation[8] spans 0.5-2.5 mm d^{-1}, and average water availability is of minimal concern (except regionally during droughts[9]). For example, 2015 data for Iowa[10] show that of total withdrawals of about 390 Mgal d^{-1}, irrigation and livestock use 35 and 165 Mgal d^{-1} respectively, or 0.1-0.5 of the total individually or jointly. A $\sigma_{wat} \approx [0.1, 0.5]$ range is thus appropriate for the relatively lush eastern part of the U.S. Conversely, much of the west is in a chronic water deficit of 0.5-1.5 mm d^{-1}, reaching as high as [11] 3-4 mm d^{-1} in the Central Valley of California, the source of most U.S. fresh produce. It thus makes sense to focus on California, where about 80% of water consumption is used for food production [7], and the Central Valley in particular. Of the nearly 26 billion gallons of 2015 freshwater withdrawals in California, 19 billion, 74%, were used for irrigation[12]. In Fresno county, archetypical of the Central Valley and at its heart, agriculture accounts for 96% of total water use. A $\sigma_{wat} \approx [0.75, 0.96]$ range is thus appropriate for the vegetable and nut producing Central Valley. As for the expected ρ_{wat} range, we first note that water use per g of U.S. beef protein is about 10 and 40 times higher [4] than those of dairy and wheat. Considering categorical global per kcal means [13] and—in recognition of the global nature of food trade—global data [13], we note that the most water intense category, bovine meat, uses about 20 times as much water as the least intensive categories, starchy roots and cereals. A $\rho_{\text{wat}} \approx [10,40]$ range is thus fitting for the arid west. For the east, the range is lower both because the far smaller water stress (evapotranspiration minus precipitation) and the narrower range of the prevalent crops. All the most water intensive crops so characteristic of the west—notably almonds, pistachios or hazelnuts—are rare and unimportant in the east. The same holds on a per g protein basis, with big users—e.g., melons, tomatoes or citrus trees—mostly or completely absent from the eastern regime. The crops that are ubiquitous in the east span roughly 2 to 15 liter per g protein, justifying $\rho_{\text{wat}} \approx [7,8]$ for the eastern regime. Using these values,

$$I_{\text{wat}}{}^{\text{east}} \sim (0.10 \text{ to } 0.50) \times (7 \text{ to } 8) \sim (1 \text{ to } 4),$$

$$I_{\text{wat}}{}^{\text{west}} \sim (0.75 \text{ to } 0.96) \times (10 \text{ to } 40) \sim (7 \text{ to } 38).$$

Calculating I_{soil} for contributions to soil loss. Topsoil erosive loss [14] has not yet entered lay persons environmental discourse to the same degree as the burdens discussed above, but is clearly globally important [15] and potentially locally decisive [15]. Because of the trivially low land use for human dwellings [16], most soil erosion enhancement beyond natural rates is due to agriculture and forestry. Areally, agriculture occupies 55% of U.S. land area to non-grazed forestry's 22% [17]. As for erosion rates, while naturally widely varied, they are on average about an order of magnitude higher in croplands than in managed forests[15, 18, 19]. Jointly these values indicate that agriculture accounts for about $(0.55 \times 1)/(0.55 \times 1 + 0.22 \times 0.1) \approx 0.96$ of the full problem, i.e., $\sigma_{\text{soil}} \approx 0.95$ to 1. The expected range of soil loss rates ρ_{soil} is most naturally derived from variability not among individual food items, but among agricultural practices [20], as follows. Numerous soil sparing strategies—e.g., biodynamic, organic, no- or low-till— exist [21] or are experimentally examined [22]. Yet all fundamentally stem from recognizing soils as a nexus [23] of biogeochemistry, geology, hydrology and meteorology, and from emphasizing the centrality of soil microbiota to mediating and catalyzing [23] the interactions among those processes. A natural distinction for quantifying ρ_{soil} is thus between conventional—synthetic agrochemical-based, regularly mechanically disturbed—intensive agriculture, and any of the alternative, soil sparing approaches. A 2-decade study of a small Oklahoma watershed revealed [24] respective mean annual erosion rates of 2260 and 5700 kg ha^{-1} y^{-1} for conservation disk-tilled and moldboard plowed systems, 8- and 21-fold increases relative to the rate of the no-till reference system, 275 kg ha^{-1} y^{-1}. An earlier synthesis [25] of tens of "fair comparisons" revealed average erosion rates under conventional cultivation 32 times higher than those characterizing conservation cultivation, with some individual comparisons exceeding 7,000-fold enhancement. Excluding such extreme and possibly suspect values, $\rho_{\text{soil}} \approx$ 8-to-50 is conservatively reasonable. Putting these values together,

$$I_{\text{soil}} \sim (0.95 \text{ to } 1.0) \times (8 \text{ to } 50) \sim (8 \text{ to } 50).$$

References

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