Supporting Information

Energy and protein feed-to-food conversion efficiencies in the US and potential food security gains from dietary changes

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1. Outline

The Supporting Information gives details on some of the terms and calculations presented in the manuscript and refers to the accompanying spreadsheet, which details all values and derivations. This documentation discusses the calculation of the dietary shift potential (section 2), the Sankey diagrams (Figures 1 and 2; section 3) and leading parameters in the animal-based portion of the American food system (section 4). The parameters used in calculating the calories and protein pathways (Figure 1 and 2) as well as major parameters in livestock husbandry and feed consumption (Table S1) are based on and update Eshel et al. (Eshel *et al* 2015, 2014). Feed composition information is based exclusively on NRC data (National Research Council 2000, 1982). The spreadsheet file is divided into several major subsections (see 'Table of Contents' tab) for convenience, each codified by a unique color: main results, food consumption data, livestock feed and resource usage, feed nutrient composition, Nitrogen, Water, GHG, and crops' data.

2. The dietary shift potential

2.1 The choice of poultry as the considered substitute

We use poultry as the replacement food in our food availability gain calculations for several reasons. First, US poultry consumption has been rising in recent decades substituting beef (Daniel *et al* 2011), suggesting it can serve as a plausible replacement. In addition, poultry incur the least environmental burden amongst the major meat categories and thus the calculation of the dietary shift potential presented here serves as an upper bound on possible food gains achievable by any substitution within the meat portion of the MAD (Mean American Diet).

Plant-based diets can also serve as a viable replacement for animal products, and confer larger mean environmental (Eshel *et al* 2014, 2016) and food availability gains. Recognizing that the majority of the population will not easily become exclusive plant eaters, here we choose the intermediate, less radical and perhaps more practical scenario of replacing the environmentally most costly beef with the more resource efficient poultry. We also refer to an independent calculation with a plant-based alternative diet as a substitute (Eshel *et al* 2016).

Finally, poultry stands out in its high kcal g^{-1} and g protein g^{-1} values and its desirable nutritional profile. Per calorie, it can deliver more protein than beef while delivering as much or more of the other essential micronutrients (Figure S1). While it is tricky to compare the protein quality of beef and poultry, we can use the biological value (modified essential amino acid index and chemical score index (Ihekoronye 1988)) and the Protein Digestible Corrected Amino Acid Score (PDCAAS), the protein indicator of choice of the FAO. Within inevitable variability, the protein quality of poultry is similar to that of beef using both metrics (Suárez López *et al* n.d., Barrón-Hoyos *et al* 2013, Sarwar 1987, Ihekoronye 1988). While the FAO has recently introduced an updated protein quality score (DIAAS – digestible indispensable amino acid score) (FAO Food and Nutrition Paper No. 92 2011), no reliable DIAAS data comparing beef and poultry exists.

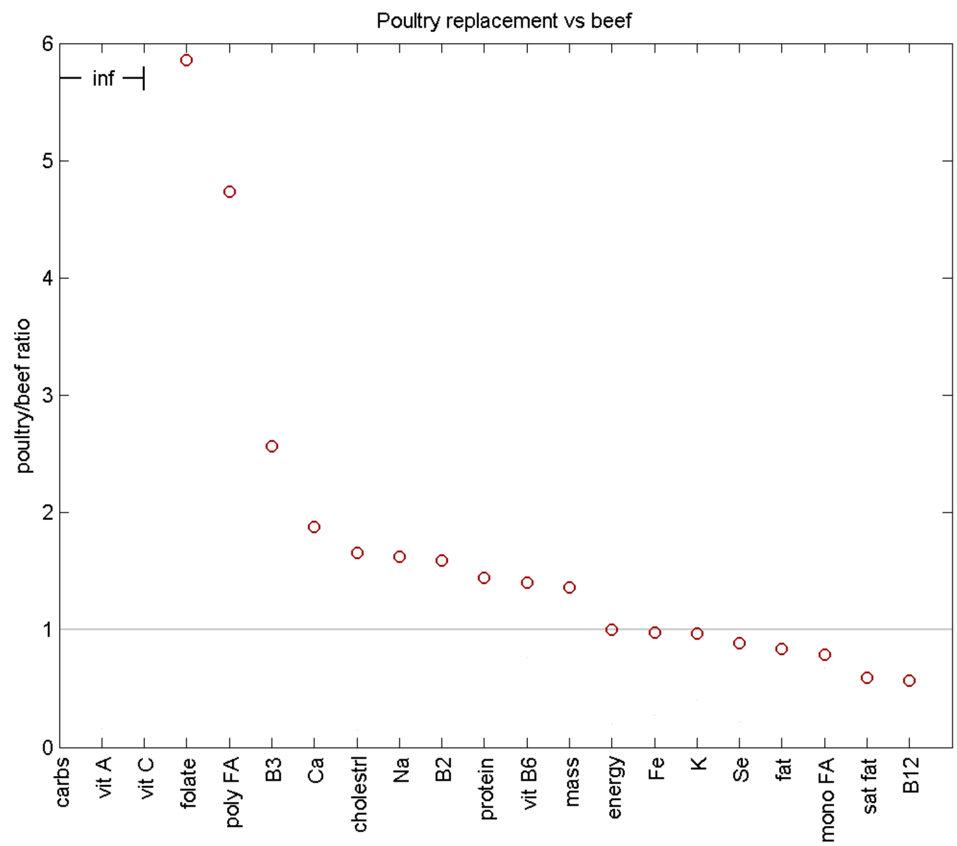

Figure S1. Poultry:beef nutritional ratios of beef and its isocaloric poultry replacement. For each nutrient (horizontal axis) the value reported along the vertical axis is poultry replacement content divided by the content in beef of the same caloric content. For the first three nutrients, the ratio is infinite because beef does not contain them. Values are derived from USDA's food composition tables (USDA AGS 2016).

2.2 Calculating the dietary shift potential

The dietary shift potential is

$$\Delta P_{a \to b} = \frac{\overbrace{P_{us}\,(l_a - l_b)}^{\text{per capita land gain}}}{\underbrace{l_{MAD} - (l_a - l_b)}_{\text{updated per capita MAD land requirement}}} \tag{1}$$

In Eq. 1, the left hand side ($\Delta P_{a \to b}$) is the number of additional people that can be fed on land spared by the replacement of food item a with food item b. P_{US}≈300 million denotes the 2000-2010 mean US population, l_a is the annual per capita land area for producing a given amount of calories of food item a*;* and l_b is the annual per capita land area needed to produce the same number of calories of food item b. This definition can be applied on a per protein instead of a per calorie basis. Also, the calculation can be applied for the substitution of whole diets rather than specific food items.

To derive the mean per capita land requirement of MAD (denoted l_{MAD}) we calculate the land needed to produce each of the plant and animal based items of the MAD. We convert a given per capita plant item mass to land requirement by dividing the consumed mass of each item by its corresponding average national yield (loss adjusted mass produced per unit area). With these item-specific land requirements for all plant items, the full diet land needs are simply the sum of these requirements over all items (see supplementary data). The per capita land requirements of the animal based MAD categories (e.g., $l_{poultry}$, l_{beef}) are based on our previous studies (Eshel *et al* 2014, 2015).

Given poultry's modest land requirements, some land that can sustain additional people on a MAD will be spared by replacing beef with caloric- or protein-equivalent poultry amount. We denote by c_{item} the caloric MAD consumption of an item. For the calculation of the substitution of beef with poultry, the per capita land area of poultry is multiplied by the caloric (or protein) MAD consumption ratio $c_{beef}/c_{poultry}$ to enable an accurate substitution. This ratio, the per capita caloric beef:poultry consumption ratio in the MAD, is equal to 1.2 (supplementary spreadsheet 'dietary shift potential' tab cell L11). For the dietary shift potential for protein, this ratio is replaced by the ratio of beef to poultry protein contribution to the MAD, equal to 0.6 (supplementary spreadsheet 'dietary shift potential' tab cell L29).

Using Eq. 1, the caloric dietary shift potential of beef (supplementary spreadsheet 'dietary shift potential' tab cell M11) is:

$$\Delta P_{beef \to poultry} = \frac{296 \times 10^6 \text{cap} \times \left(0.3 \frac{\text{ac}}{\text{cap}} - 0.06 \frac{\text{ac}}{\text{cap}} \times \frac{190\text{kcal}}{158\text{kcal}}\right)}{0.8 \frac{\text{ac}}{\text{cap}} - 0.3 \frac{\text{ac}}{\text{cap}} + 0.06 \frac{\text{ac}}{\text{cap}} \times \frac{190\text{kcal}}{158\text{kcal}}} \approx 120 \times 10^6 \text{cap}$$

For the beef replacement calculation, the alternative energy or protein mass (the light orange arrows in figure 3) is the sum of two terms: (1) calories/protein of poultry for the entire US population (replacing the contribution of beef's calories or protein in the MAD); and (2) MAD calories/protein that the spared lands can sustain (national feed land supporting beef, minus the land needed to produce (1)). The MAD calories that the spared lands can sustain is calculated by multiplying the spared land area by the caloric yield of cultivating the full MAD (with poultry replacing beef), ≈1700 Mcal (ac yr)$^{-1}$. The national annual caloric flux (added calories per year) when substituting beef for poultry is

$$C^{\mathrm{nat.}}_{\mathrm{beef}\rightarrow\mathrm{poultry}} = 365P_{\mathrm{US}}c_{\mathrm{beef}} + 365c_{\mathrm{MAD}}\frac{P_{\mathrm{US}}\left(l_{\mathrm{beef}}-l_{\mathrm{poultry}}\frac{c_{\mathrm{beef}}}{c_{\mathrm{poultry}}}\right)}{l_{\mathrm{MAD}}-\left(l_{\mathrm{beef}}-l_{\mathrm{poultry}}\frac{c_{\mathrm{beef}}}{c_{\mathrm{poultry}}}\right)} \qquad (2)$$

where the above equation contains the per capita daily caloric consumption and annual land requirements (c and l, respectively) of poultry, beef and full MAD. As in Eq. 1, P_{US} denotes the 2000-2010 mean US population. The first and second terms on the right hand side of Eq. 2 are terms (1) and (2) of the above discussion, respectively. See supplementary spreadsheet 'dietary shift potential' tab cell J11 for further details.

To derive the difference between the above replacement caloric flux and that produced by beef (percentages next in figure 3), we subtract the national consumed animal food calories of beef from the above equation. Since $365P_{\mathrm{US}}c_{\mathrm{beef}}$ is the national annual beef calories consumed, the difference between the replacement caloric flux and beef's caloric flux (supplementary spreadsheet 'dietary shift potential' tab cell K11 in percentage) is given by:

$$C^{\mathrm{nat.}}_{\mathrm{beef}\rightarrow\mathrm{poultry}} - C^{\mathrm{nat.}}_{\mathrm{beef}} = 365c_{\mathrm{MAD}}\frac{P_{\mathrm{US}}\left(l_{\mathrm{beef}}-l_{\mathrm{poultry}}\frac{c_{\mathrm{beef}}}{c_{\mathrm{poultry}}}\right)}{l_{\mathrm{MAD}}-\left(l_{\mathrm{beef}}-l_{\mathrm{poultry}}\frac{c_{\mathrm{beef}}}{c_{\mathrm{poultry}}}\right)} \qquad (3)$$

As noted above, the quotient on the right hand gives the number of extra people that can be fed, as also reported in Figure 3. An analogous calculation replacing calories with protein mass yields the protein dietary shift potential shown in Figure 3b. The current calculation of the dietary shift potential also enables calculating the food availability gains associated with any partial replacement. Figure S2 depicts the relation between the dietary shift potential (additional people that can be fed a full MAD diet) and the percentage of national beef calories (from MAD) replaced with poultry. The relation is not perfectly linear as the updated MAD land requirement in the denominator changes as the fraction of poultry to beef is varied.

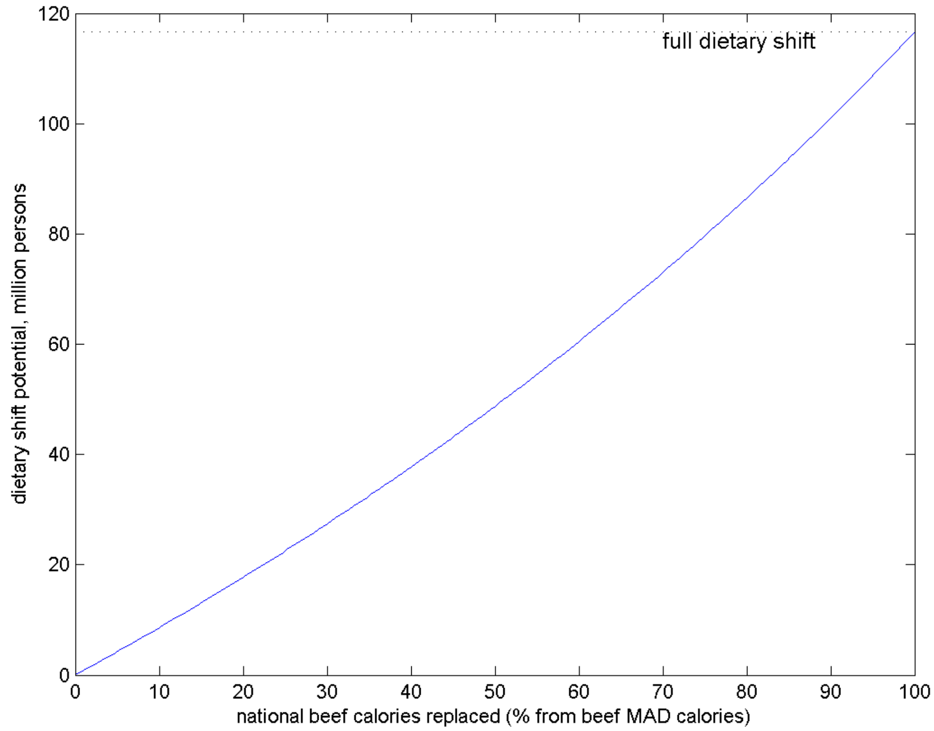

Figure S2. The relation between the dietary shift potential (additional people that can be fed a full MAD diet when substituting beef with poultry) and the percentage of national beef calories (from MAD) replaced with poultry**.**

As a benchmark with which to compare the beef to poultry results, we also calculated the dietary shift potential for the substitution of beef with a plant based alternative based on the methodology developed in Eshel *et al* (2016). In that study, we derive plant based diets with similar energy and protein values as beef (considering 65 leading plant items consumed by the average American) that minimize land requirements with the mass of each plant item set to $\leq$15 g d^{-1} to ensure dietary diversity. We find that legume and nuts dominated plant based diets substitute beef with a dietary shift potential of $\approx$190 million individuals (Excel 'dietary shift potential' tab cell J40).

3. Sankey diagram values

The Sankey diagram values and calculations are detailed in the supplementary spreadsheet 'sankey' tab for energy (cells E8-Q27) and protein (cells E30:Q55), and reported in Figures 1 and 2, respectively. For instance, the annual caloric contribution of concentrates is 590 Pcal (cell G15, where Pcal=10^{12} kcal). Of that total, 134 Pcal (cell G22) are calories fed to pork, yielding 12 Pcal loss adjusted edible pork calories (cell O22). This net loss of 122 Pcal (cell N22) translates to conversion efficiency of 9% (cell P22), as indicated in the upper part of Figure 1 when moving from the left hand side (feed) to the right (loss adjusted consumed pork). The 'sankey' tab similarly details the contribution of the other feed classes (processed roughage and pasture) and their partitioning into dairy and beef (rows 20 and 24).

Our current calculation of the caloric and protein feed content relies exclusively on NRC data (National Research Council 1982, 2000) and takes note of the different metabolic energies of feed for each livestock category. This is a major update to our previous papers (Eshel *et al* 2014, 2015) which relied on a less comprehensive reference. Updating our previous calculation we now include distillers' grains in the byproducts category (see supplementary spreadsheet 'byproducts' tab). It should be noted that these updates lend more robustness to our current results but give quantitatively very similar results (within the uncertainty range) to previous results (Eshel *et al* 2014, 2015).

4. Leading parameters of livestock production in the USA

Table S1 (an elaboration of Table 1) summarizes key energy and protein properties and conversion attributes of the animal portion of the US food system, highlighting the differences among animal categories. The full calculation of all these parameters is performed in supplementary spreadsheet 'Table 1' tab.

For example, protein conversion efficiency (protein food:protein feed) varies 12-fold from beef's 2.5% to eggs' 31%. Calories conversion efficiency (energy food:energy feed) is lowest, 3%, for beef and highest, 17%, for eggs and dairy. Beef's efficiency in converting feed mass to added live weight, feed energy to food energy and feed protein to food protein, is much lower than of the other animal categories. Compared to those of beef, the mean efficiencies of the other animal categories are 6, 5, and 8 times higher, respectively.

Table S1. Key parameters used in evaluating US feed allocation among animal categories (Eshel *et al* 2015) and energy (caloric) and protein efficiency. LW = live weight; EW = edible weight (USDA reported retail boneless edible weight); CW = USDA reported loss-adjusted consumed weight. N/A, denotes "not applicable" as the parameter is relevant only for CW. Feed caloric content refers to metabolizable energy and feed protein content refers to crude protein. Detailed references and calculations supporting this table are in the supplementary spreadsheet as detailed below with examples presented in section S4. This table is an elaboration of Table 1.

#	parameter	units	beef	poultry	pork	dairy	eggs
1	feed intake per LW	kg/kg LW	14 ± 4	1.9 ± 0.4	3.1 ± 1.3	N/A	N/A
2	feed intake per EW	kg/kg EW	36 ± 13	4.2 ± 0.8	6 ± 2.5	N/A	N/A
3	feed intake per CW	kg/kg CW	49 ± 9	5.4 ± 1.4	9 ± 4	2.6 ± 0.6	2.4 ± 1.2
4	EW	% of LW	40 ± 7	46 ± 3	52 ± 5	N/A	N/A
5	feed caloric content	kcal/g	2.3 ± 0.6	3.4 ± 1.4	3.6 ± 2	2.8 ± 0.9	3.4 ± 2.4
6	food caloric content	kcal/g	3.2 ± 0.3	2.3 ± 0.1	2.8 ± 0.2	1.2 ± 0.1	1.4 ± 0.1
7	caloric conversion efficiency	%	2.9 ± 0.7	13 ± 4	9 ± 4	17 ± 4	17 ± 9
8	feed protein content	%	12 ± 3	17 ± 7	17 ± 11	15 ± 5	17 ± 12
9	food protein content	%	15 ± 2	20 ± 2	14 ± 1.4	6 ± 0.6	13 ± 1.3
10	protein conversion efficiency	%	2.5 ± 0.6	21 ± 7	9 ± 4.5	14 ± 4	31 ± 16
11	feed calories per unit of protein CW	MJ/g	3.2 ± 0.7	0.4 ± 0.13	0.9 ± 0.5	0.5 ± 0.15	0.3 ± 0.14
12	feed calories per unit of protein EW	MJ/g	2.4 ± 0.6	0.3 ± 0.10	0.6 ± 0.3	N/A	N/A

We calculate livestock feed intake per live weight (LW) gain (Table S1, row 1 and 'Table 1' tab cells C5-7) by dividing total dry matter (DM) intake of each animal category ('Animal Partitioning' tab) by slaughtered mass of each category. The latter is calculated by multiplying slaughtered head counts ('slaughter inv' tab line 142) by average slaughter weight per head in each animal category ('slaughter inv' tab line 145). For example, pork's feed intake per live weight is as follows:

$$\text{Feed intake per LW}_{\text{pork}} = \frac{91{,}236\times10^{6}\ \text{DM lb}}{106\times10^{6}\times280\ \text{lb}} = 3.1\ \ \frac{\text{DM kg}}{\text{LW kg}} \tag{4}$$

where pork's DM intake appears in 'Animal Partitioning' tab as a sum of cells Z21 and AA21 and its slaughter head count and slaughter weight per head are presented in 'slaughter inv' tab cell I142 and I145 respectively.

Feed intake per edible weight (Table S1, row 2 and 'Table 1' sheet cells C19-21) is the feed intake per LW of each animal category (Table S1, row 1) divided by the edible portion of live weight (Table S1, row 4). Pork's feed intake per edible weight, e.g., is

$$\text{Feed intake per EW}_{\text{pork}} = \frac{3.1 \text{ DM kg/LW kg}}{52\%} = 6 \ \frac{\text{DM kg}}{\text{EW kg}} \tag{5}$$

We obtain feed intake per CW (consumed loss adjusted weight; Table S1, row 3 and 'Table 1' tab cells C13-17) by dividing total DM intake of each animal category ('Animal Partitioning' tab L19-23) by its loss-adjusted consumed total food mass. The latter is calculated by dividing total loss adjusted food calories of each animal category ('USA Cal-Protein Intake' tab F25, H25, J25, L25, N25) by the respective caloric density ('Caloric density' tab cells J8-12). For example, pork's feed intake per CW is

$$\text{Feed intake per CW}_{\text{pork}} = \frac{83{,}025{\times}10^6 \text{DM lb} \times 0.45\frac{\text{kg}}{\text{lb}} \times 2.83 \ \frac{\text{Mcal}}{\text{edible kg}}}{12{,}127{\times}10^6 \text{ Mcal}} \approx 9 \ \frac{\text{DM kg}}{\text{CW kg}} \tag{6}$$

Edible weight (EW) ratio (Table S1, row 4 and 'Table 1' sheet cells C9-11) is the edible portion of the live weight of each animal category. We derive these values by dividing national retail edible weight consumption (per capita annual consumption multiplied by total population) by slaughter mass weight of each category. For pork, e.g., this value is

$$\text{EW}_{\text{pork}} = \frac{47.2 \ \frac{\text{lb}}{\text{cap}} \times 296{\times}10^6 \text{ cap}}{106{\times}10^6{\times}280 \text{ lb}{\times}{\times}91\%} \approx 0.52 \tag{7}$$

where the 91% is a domestic disappearance correction factor ('PartitioningResources' cell B23) inserted to convert total slaughter weight to domestically-consumed total slaughter weight.

The average caloric content of feed (Table S1, row 5 and 'Table 1' sheet cells C23-27) is derived by summing all feed calories from all feed classes per animal category ('PartitioningResources' tab cells AQ6-10) and dividing it by total DM intake of each category ('Animal Partitioning' tab L19-23). For pork, this is (using 'Animal Partitioning' tab cell L21, 'PartitioningResources' tab cell AQ8 and conversion factor)

$$\text{Feed caloric content}_{\text{pork}} = \frac{134{,}037 \times 10^6 \text{ Mcal} \times 2.2\frac{\text{lb}}{\text{kg}}}{83{,}025{\times}10^6 \text{ DM lb}} = 3.6 \ \frac{\text{Mcal}}{\text{kg}} \tag{8}$$

We derive the caloric content of all animal based food items (Table S1, row 6 and 'Table 1' tab cells C29-33) by comparing total annual national caloric intake ('USA Cal-Protein Intake' tab cells F25, H25, J25, L25, N25 or 'Caloric density' tab cells L8-12) with loss adjusted weight consumption per capita per year ('Caloric density' tab cells M8-12) multiplied by total population ('Caloric density' tab cell G5).

For example, pork's caloric content is (using values from 'Caloric density' tab cells L10, M10, and G5, and conversion factors)

$$\text{Food caloric content}_{\text{pork}} = \frac{12{,}127\times10^{6}\frac{\text{Mcal}}{\text{yr}}\times2.2\frac{\text{lb}}{\text{kg}}}{296\times10^{6}\text{cap}\times31.9\,\frac{\text{lb}}{\text{cap}*\text{yr}}} = 2.8\ \frac{\text{Mcal}}{\text{kg}} \tag{9}$$

Caloric conversion efficiencies (Table 1, row 7 and 'Table 1' sheet cells C35-39) follow Eshel et al. (2014), calculated by dividing total consumed food calories of each category ('USA Cal-Protein Intake' tab cells F25, H25, J25, L25, N25) by total feed calories of each animal category ('PartitioningResources' tab cells AQ6-10). For pork, e.g., using values in 'USA Cal-Protein Intake' tab cell J25 (food calories) and 'PartitioningResources' tab cell AQ8 (feed calories), this is

$$\text{caloric efficency}_{\text{pork}} = \frac{12{,}127\times10^{6}\ \text{Mcal}}{134{,}037\ \times10^{6}\ \text{Mcal}} = 0.09 = 9\% \tag{10}$$

Like calories, feed protein content (Table 1, row 8 and 'Table 1' sheet cells C41-45) is the ratio of total feed protein from all feed classes for each animal category ('PartitioningResources' tab cells BC6-10) to total DM intake of each category ('Animal Partitioning' tab cells L19-23). For pork, using 'Animal Partitioning' tab cell L21 and 'PartitioningResources' tab cell BC8, it is

$$\text{feed protein content}_{\text{pork}} = \frac{14{,}412\ \times10^{6}\ \text{lb}}{83{,}025\times10^{6}\ \text{DM lb}} = 0.17 = 17\% \tag{11}$$

Protein content of animal based food items (Table S1, row 9 and 'Table 1' sheet cells C47-51) are from Smil (2001) except dairy, which we calculate by weighted averaging all MAD dairy products and their corresponding protein content (tab 'dairy protein calc' cell C61). For pork this value is 14% ('Table 1' sheet cell C49).

We calculate protein conversion efficiencies (Table S1, row 10 and 'Table 1' sheet cells C53-57) as the ratio of total consumed food protein of each category ('USA Cal-Protein Intake' tab cells S25, U25, W25, Y25, AA25) to total feed protein intake of each animal category ('PartitioningResources' tab cells BC6-10). For pork, e.g., the values were derived from 'USA Cal-Protein Intake' tab cell W25 and 'PartitioningResources' tab cell BC8. The calculation appears both as Eq. 12 or the reciprocal of 'PartitioningPerProtein' tab cell P19:

$$\text{protein conversion efficency}_{\text{pork}} = \frac{599\ \times10^{6}\ \text{kg}\times2.2\frac{\text{lb}}{\text{kg}}}{14{,}412\ \times10^{6}\ \text{lb}} = 0.092 \approx 9\% \tag{12}$$

We calculate feed calories per unit of protein CW food (in MJ/g, Table S1 row 11 and 'Table 1' sheet cells C63-67) as the ratio of feed calories per animal category ('PartitioningResources' tab cells AQ6-10) to loss adjusted food protein intake of each category ('USA Cal-Protein Intake' tab cells S25, U25, W25, Y25, AA25). For pork, e.g., Eq. 13 presents the values and calculation. We take the feed calories from 'PartitioningResources' tab cells AQ8 and loss adjusted pork protein from 'USA Cal-Protein Intake' tab cell W25. Alternatively, the value is derived in 'PartitioningPerProtein' tab cell Y19 (in kcal per g).

$$\text{feed calories per CW protein}_{\text{pork}} = \frac{134{,}037 \times 10^{6}\,\text{Mcal} \times 4.2\frac{\text{MJ}}{\text{Mcal}}}{599 \times 10^{6}\,\text{kg} \times 1000\frac{\text{g}}{\text{kg}}} = 0.9\,\frac{\text{MJ}}{\text{g}} \qquad (13)$$

We compute feed calories per unit of protein EW meat (in MJ/g, Table S1 row 12 and 'Table 1' sheet cells C59-61) as feed calories per loss adjusted protein (Table S1 row 11) multiplied by the ratio of CW/EW for each animal category. We derive the latter coefficient for each animal category by dividing its per capita loss adjusted food weight with its retail weight ('caloric density' tab cells I8:I12). For example, Eq. 14 summarizes this calculation for pork:

$$\text{feed calories per EW protein}_{\text{pork}} = 0.9\,\frac{\text{MJ}}{\text{g CW}} \times 0.7\,\frac{\text{g CW}}{\text{g EW}} = 0.6\,\frac{\text{MJ}}{\text{g EW}} \qquad (14)$$

References

Barrón-Hoyos J M, Archuleta A R, Falcón-Villa M del R, Canett-Romero R, Cinco-Moroyoqui F J, Romero-Barancini A L and Rueda-Puente E O 2013 Protein Quality Evaluation of Animal Food Proteins by *In-Vitro* Methodologies *Food Nutr. Sci.* **04** 376–84 Online: http://www.scirp.org/journal/PaperInformation.aspx?PaperID=29737

Daniel C R, Cross A J, Koebnick C and Sinha R 2011 Trends in meat consumption in the USA. *Public Health Nutr.* **14** 575–83 Online: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3045642&tool=pmcentrez&rendertype=abstract

Eshel G, Shepon A, Makov T and Milo R 2014 Land, irrigation water, greenhouse gas and reactive nitrogen burdens of meat, eggs & dairy production in the United States *Proc. Natl. Acad. Sci. U. S. A.* **111** 11996–2001

Eshel G, Shepon A, Makov T and Milo R 2015 Partitioning United States' Feed

Consumption Among Livestock Categories For Improved Environmental Cost Assessments *J. Agric. Sci.* **153** 432–45

Eshel G, Shepon A, Noor E and Milo R 2016 Environmentally Optimal, Nutritionally Aware Beef Replacement Plant Based Diets. In press *Environ. Sci. Technol.*

FAO Food and Nutrition Paper No. 92 2011 *Dietary protein quality evaluation in human nutrition, Report of an FAO Expert Consultation* (Auckland, New Zealand) Online: http://www.fao.org/ag/humannutrition/35978-02317b979a686a57aa4593304ffc17f06.pdf

Ihekoronye A I 1988 Estimation of the biological value of food proteins by a modified equation of the essential amino acid index and the chemical score *Food / Nahrung* **32** 783–8 Online: http://doi.wiley.com/10.1002/food.19880320818

National Research Council 2000 *Nutrient Requirements of Beef Cattle: Seventh Revised Edition: Update 2000* (Washington, DC: The National Academies Press)

National Research Council 1982 *United States-Canadian Tables of Feed Composition: Nutritional Data for United States and Canadian Feeds, Third Revision* (Washington D.C., USA)

Sarwar G 1987 Digestibility of Protein and Bioavailability of Amino Acids in Foods, Effects on Protein Quality Assessment *World Rev. Nutr. Diet.* **54** 26–70 Online: https://www.karger.com/Article/Pdf/415302

Smil V 2001 *Feeding the World: A Challenge for the Twenty-First Century* (The MIT Press)

Suárez López M M, Kizlansky A and López L B Evaluación de la calidad de las proteínas en los alimentos calculando el escore de aminoácidos corregido por digestibilidad *Nutr. Hosp.* **21** 47–51 Online: http://scielo.isciii.es/scielo.php?script=sci_arttext&pid=S0212-16112006000100009&lng=es&nrm=iso&tlng=en

USDA AGS 2016 USDA National Nutrient Database for Standard Reference, Release 28 Online: https://ndb.nal.usda.gov/