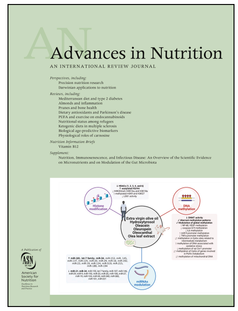
Journal Pre-proof




Perspective: The place of pork meat in sustainable healthy diets

Adam Drewnowski

PII: S2161-8313(24)00047-4
DOI: https://doi.org/10.1016/j.advnut.2024.100213
Reference: ADVNUT 100213

To appear in: *Advances in Nutrition*

Received Date: 8 September 2023
Revised Date: 13 March 2024
Accepted Date: 15 March 2024

Please cite this article as: A. Drewnowski, Perspective: The place of pork meat in sustainable healthy diets, *Advances in Nutrition*, https://doi.org/10.1016/j.advnut.2024.100213.

This is a PDF file of an article that has undergone enhancements after acceptance, such as the addition of a cover page and metadata, and formatting for readability, but it is not yet the definitive version of record. This version will undergo additional copyediting, typesetting and review before it is published in its final form, but we are providing this version to give early visibility of the article. Please note that, during the production process, errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

© 2024 Published by Elsevier Inc. on behalf of American Society for Nutrition.

Journal Pre-proof

Advances 23-0307R3 03122024

**Perspective: The place of pork meat in sustainable healthy diets**

**Adam Drewnowski** [1]

[1] Center for Public Health Nutrition, University of Washington, Seattle, WA 98195-3410, USA

**Corresponding author:** Adam Drewnowski

Email: adamdrew@uw.edu

**Running head:** Pork in sustainable healthy diet

**Conflicts of Interest:**

AD is the original developer of the Naturally Nutrient Rich (NNR) and the Nutrient Rich Food (NRF) nutrient profiling models and a member of scientific advisory panels for National Pork Board, Nestlé, FrieslandCampina, BEL, and Carbohydrate Quality Panel supported by Potatoes USA and has worked with Ajinomoto, FoodMinds, KraftHeinz, Nutrition Impact LLC, Nutrition Institute, PepsiCo, and Samsung on quantitative ways to assess nutrient density of foods.

**Sources of support:**

Analyses of publicly available USDA, FAO and World Bank data were supported by the National Pork Board. The funders were not involved in the development of databases, analytical models, data analysis or interpretation, manuscript preparation or the decision to submit the manuscript for publication.

Journal Pre-proof

Journal Pre-proof

**Abbreviations**

DGA Dietary Guidelines for Americans

DIAAS Digestible Indispensable Amino Acid Score

DV Reference Daily Values

EPA Environmental Protection Agency

FAO Food and Agriculture Organization of the United Nations

FAOSTAT Food and Agriculture Organization Statistical Database

FCID Food Commodity Intake Database

FDA Food and Drug Administration

FNDDS Food and Nutrient Database for Dietary Studies

FredHutch Fred Hutchinson Cancer Research Center

GHGE Greenhouse Gas Emissions

LCA Lifecycle Analysis

LMIC Lower and Middle Income Countries

nFU nutrition Functional Unit

PDCAAS Protein Digestibility Corrected Amino Acid Score

PPP Purchase to Plate Pricing tool

SNAP Supplemental Nutrition Assistance Program

SR-28 Standard Reference database 28th edition

TFP 2021 Thrifty Food Plan 2021

Journal Pre-proof

Journal Pre-proof

USDA United States Department of Agriculture

WHO World Health Organization

WWEIA What We Eat in America

Journal Pre-proof

Journal Pre-proof



## Abstract (281 words)

The food systems sustainability framework has four domains: nutrition, economics, environment, and society. To qualify as sustainable, individual foods and total diets need to be nutrient-rich, affordable, environmentally friendly, and socially acceptable. Pork is the most consumed meat globally, providing high-quality protein and several priority micronutrients. With research attention focused on plant-based diets, it is time to assess the place of pork meat protein in the global sustainability framework.

First, not all proteins are equal. The US Department of Agriculture (USDA) category of protein foods includes meat, poultry and fish, eggs, beans and legumes, and nuts and seeds. These protein sources have different protein digestibility profiles, different per calorie prices, and different environmental footprints, measured in terms of greenhouse gas emissions (GHGE). Second, most analyses of animal-source proteins combine beef, pork and lamb into a single category of red meat. Beef, pork and lamb have different nutrient profiles, different protein costs, and different impacts on the environment. Future analyses of nutrient density and monetary and carbon cost of alternative diets would do well to separate pork from beef, lamb, and chicken.

There are also different profiles of global food demand. Prior analyses of global FAOSTAT food balance sheets joined with World Bank country incomes have consistently shown that rising incomes across lower-and middle-income countries (LMIC) create a growing demand for meat to replace the traditional plant proteins. Most of the observed increase has been for pork and chicken rather than beef. This ongoing LMIC protein transition toward more animal proteins may be irreversible as long as incomes grow. The present analyses explore the place of pork in sustainable healthy diets worldwide, given the need for high quality protein and the predictable patterns of global food demand.


Journal Pre-proof

**Keywords:** Fresh pork, protein, national food prices, affordability, greenhouse gas emissions (GHGE), sustainability, protein transition, peak meat consumption, Bennett's Law.

**Statement of Significance**: Most studies on sustainable healthy diets do not distinguish among different types of red meat. Separating pork from other red meats, this Perspective explore the place of fresh pork in the sustainability framework, looking at protein content, affordability, and greenhouse gas emissions based on analyses of publicly available data from the USDA, FAO, and the World Bank.

Journal Pre-proof

## 1. Introduction

Animal protein from red meat has high monetary and environmental costs (1,2). The high carbon footprint of meat proteins (2), combined with intensive land and water use, has led to concerns that meat production is not sustainable in the long term (3,4). With the current global emphasis on plant-forward diets (5,6), the place of animal proteins in human diets needs to be examined more closely with reference to nutrient density, affordability, and impact on the environment (7).

The present Perspective is focused on pork meat. Pork is first in global per capita meat consumption (8). Pork meat provides high quality protein, several priority micronutrients, is affordable, and in most societies culturally acceptable (9,10). Yet pork meat is largely missing from the global nutrition and sustainability discourse and is rarely mentioned in the Dietary Guidelines for Americans (DGA) (11). Rather, pork meat in both research and policy documents is typically assigned to the category of red meat (12,13). As attention turns to the forthcoming US Dietary Guidelines 2025-30, it is important to separate pork meat from other protein sources and from other meats, where existing data allow.

Pooling pork, beef, and lamb is very common in nutrition and epidemiology research (12-15). Food frequency questionnaires, often used to support public health policy, typically bundle pork with beef and lamb. "Did you eat beef, pork, or lamb" is a single question on the widely used Fred Hutch food frequency questionnaire (16). The influential Nurses' Health Study and other longitudinal cohorts distinguish between fresh and processed meat but do not treat pork meat as a separate category (12,14). This may have consequences for interpreting data on diets and health outcomes. The failure to distinguish between different types of red meat, corrected only in some recent studies (17), may overlook the unique contribution of pork to the US diet, with implications for Dietary Guidelines 2025-30.

Journal Pre-proof

Journal Pre-proof


The failure to make cost distinctions among different types of red meat may also have food policy consequences. The USDA Thrifty Food Plan (TFP) market basket is the federal estimate of a lowest cost healthy diet (18). Its composition is critically important, since it is used to allocate food assistance benefits (SNAP), estimated at more than $100 billion per year (19). The last TFP revision (TFP 2021) combined beef and pork into a single category of red meat (18). Since red meat was more expensive than chicken, the TFP 2021 favored poultry as the main protein source in terms of amounts and allocated expenditures (18). Calculations based on a lower price for pork led to a different TFP market basket in an independent diet optimization study (20).

The failure to separate greenhouse gas emissions (GHGE) by meat source has implications for the future of food. Based on the reported environmental and health impacts of red meat, the influential EAT Lancet report (5) proposed a planetary health diet that was largely plant-based, with an estimated 88% of total daily calories coming from cereals, root crops, nuts, legumes, vegetables, and fruit (5). Pork was limited to 7 g/day (range 0-14g), same as beef. Higher amounts were proposed for chicken (29g) and fish (28g), both of which were viewed as healthier and more environmentally friendly than red meat.

This Perspective article aims to assess the place of fresh pork in the global sustainability framework, drawing on data from US sources and from international agencies. The present goal was to examine the sustainability of pork as a source of meat protein, considering nutrition, affordability, environmental impact, and future food demand.

## 2. Databases and analytical methods

Analyzing the place of pork in the global diet sustainability framework requires access to data from multiple domains: nutrition and health, economics, and the environment (21,22).

High-quality data on energy and nutrient content of foods came from the US Department of Agriculture (USDA) databases (23,24). The dietary component of the nationally representative National Health and Nutrition Examination Survey (NHANES 2015-16) is known as the What We Eat in America (WWEIA) study. The USDA Food and Nutrient Database for Dietary Studies (FNDDS 2015-16) contains energy and nutrient values for 6,581 foods reported as consumed by NHANES 2015-16 participants (24). Listed are individual foods and mixed dishes, prepared in a variety of ways. Food items in the FNDDS 2015-16 are aggregated into food groups, food categories and food subcategories using WWEIA 1-digit, 2-digit and 4-digit codes (25).

The protein food group in the FNNDS 2015-16 database includes animal proteins and proteins from plants. The categories are meat, poultry, fish and seafood, eggs, as well as beans, peas and legumes, soy products, and nuts and seeds (26). Dairy is another source of dietary protein, with categories defined as milk, yogurt, and cheese. WWEIA codes also include the grains group and the large category of mixed dishes, such as sandwiches, soups and mixed foods that could be meat or plant based (25). Not included in analyses were alcoholic beverages, vegetables and fruit, condiments, and snacks and sweets, all of which contained little protein.

Mean national retail prices for 3,231 FNDDS food codes were based on the 2015-2016 Purchase to Plate Price Tool (PPP) (26) and came from the TFP 2021 Supplemental files (18). As reported in the TFP 2021 (18), the more costly foods and foods purchased by NHANES participants with incomes at >350% of federal poverty had been excluded. To calculate the TFP 2021, the USDA adjusted the 2015-2016 prices for inflation to June 2021 (18).

Previously used data on greenhouse gas emissions (GHGE) for FNDDS 2015-16 foods (27) came from the Food Impacts on the Environment for Linking to Diets (dataFIELD) database and from a systematic review of life cycle assessments (LCA) published between 2005 and 2016 (28,29). The GHGE estimates were averaged across studies and were matched to commodities in the 2010 US Environmental Protection Agency (US EPA) Food Commodity Intake Database (FCID) (28,29). The FCID provides information on the amount of >500 food components in each food reported as consumed by NHANES participants (29). GHGE data for FNDDS 2015-16 foods were merged with energy, nutrients and national food prices data using food identification codes.

Data to illustrate the place of pork meat in the global food supply came from the Food and Agriculture Organization of the United Nations (FAO) FAOSTAT data repositories (30,31). At the global level, FAOSTAT (31) provides food balance sheets for selected commodities (bovine meat, pigmeat). Those data are limited to items that are part of formal trade and enter the retail market; informal commerce is not included. Food balance sheets are also used to calculate amounts of total protein, animal protein and plant protein (in kg/capita/y) that are available for human consumption. Despite their many limitations, FAO food balance sheets and other food supply data are routinely used as proxies for human food consumption (5,32).

Data on country incomes came from the World Bank (33). The World Bank classifies economies for analytical purposes into four income groups: low, lower-middle, upper-middle, and high income. The data are expressed as gross national income (GNI) per capita in U.S. dollars, converted from local currency using the World Bank Atlas method to smooth exchange rate fluctuations (33). The present analyses were based on 164 countries that had both FAO data and

World Bank incomes for the year 2019. Both sets of data are publicly available and can be downloaded from the FAO and World Bank websites, respectively.

## 3. The place of pork in the sustainability framework.

A review of the literature, combined with some original analyses, has led to these perspectives.

### 3.1 Pork meat is an excellent protein source.

First, the red meat category was separated into beef, pork, lamb, and cured meats. **Table 1** shows protein content in g/100g, energy density in kcal/100g, and the amount of dietary energy needed to obtain 50g of protein (100% reference daily value) by food category. This type of nutrients to energy calculation has been used before (34). Analyses of energy and protein content used one-way ANOVAS with Bonferroni correction for planned post hoc tests. Mean energy density of all meats was about 200-300 kcal/100 g. Mean amount of protein in pork items was 27.6 g/100 g, not significantly different from red meat or poultry but significantly above the other food categories tested.

Beef, pork, lamb, poultry, and seafood were high in protein per 100g and delivered 100% DV of protein for the least calories. At the other extreme, getting 50 g of protein from grains would require (in theory) more than 2000 kcal/day. The protein leverage hypothesis (35) suggests that humans eat to satisfy protein needs, and that foods will be consumed until protein needs have been met, regardless of energy content. If the protein leverage hypothesis is correct, that could potentially lead to an over-consumption of some foods (e.g. starches and grains) when their protein content is low.

Subsequent analyses used finer WWEIA subcategories, separating beef and ground beef, chicken and turkey, fish and shellfish, and milk, yogurt and cheese. Plant proteins were separated into beans, peas and legumes, soy products and nuts and seeds. Protein content was also calculated for bacon, cold cuts, sausages, and frankfurters. **Figure 1A** shows the relation between mean grams of protein per 100g plotted against mean energy density by WWEIA subcategory.

Most animal-source food categories in the FNDDS 2015-16 database, had a mean of >20 g of protein per 100 g. Foods that were highest in protein were pork, turkey, beef, and lamb dishes. Fresh pork items contained a mean of 25.4 g of protein per 100 g, as compared to 27.3 g/100 g for beef and 23.2g/100 g for chicken. For comparison, protein content of Greek yogurt was about 10 g/100 g, while cheeses contained about 20 g/100 g protein. Foods that provide >20% Daily Value per serving for a given nutrient are deemed to be excellent sources of that nutrient.

The amount of dietary energy needed to supply 50 g of protein depends on energy density (kcal/100 g). Meats and meat dishes contained between 150 and 300 kcal/100 g; bacon contained closer to 500 kcal/100 g, whereas nuts and seeds contained close to 600 kcal/100 g. The protein content of plant foods was generally below 10g/100 g (except for processed soy) whereas the energy and carbohydrate content were high. As a result, the protein-to-calories ratio for nuts and seeds was now below that for beans and legumes, as shown in **Figure 1B.** Foods with maximum protein percent daily values (%DV) per 100 kcal of food were pork, turkey, beef, and lamb. Mixed dishes, nuts, and seeds (and bacon) provided less protein per calorie because of their high energy density.

The present data were not corrected for PDCAAS (Protein Digestibility Corrected Amino Acid Score) (36). In general, based on available (but still limited) PDCAAS data, meat, milk and eggs have more digestible protein per 100g than plant-based proteins, including grains, seeds and nuts.

Journal Pre-proof

The USDA school lunch program requires plant proteins to have PDCAAS of >80% (37). Pork, beef, chicken, seafood and eggs and dairy have favorable PDCAAS and DIAAS values. DIAAS data for FNDDS foods are not yet available.

**3.2. Pork meat is an affordable protein source.**

Food prices that were obtained from the TFP 2021 Supplemental data files (18) were limited to about 3000 foods in all. **Figure 2** shows protein content in g/100g plotted against mean prices per 100g for each protein food category and subcategory. There was a clear separation in food prices between shellfish and other proteins and then between pork, beef, and lamb. Mean national prices for pork meat were below beef and fish and very close to chicken and turkey.

**Figure 3** shows the cost of protein foods in the TFP 2021 database, expressed per 100g of protein (that is 100% Daily Value). These are the same prices that had been used in the construction of the revised Thrifty Food Plan 2021. The protein foods, animal and plant, were now separated into categories and subcategories based on USDA codes. Shellfish were the most expensive protein source, as had also been noted in the TFP 2021 report (18). Once the red meat category was separated into components, fresh pork was closer in price to chicken and beans than it was to lamb or beef. The price for 50 g of protein from pork was not significantly different from that of poultry and eggs but significantly below other types of meat.

This price differential has consequences for the design of affordable healthy food plans. The TFP 2021 (18) market basket, developed by the USDA Center for Nutrition Policy and Promotion (CNPP), is the current federal estimate of the lowest cost healthy and nutrient adequate food plan, suitable for a standard family of 4. The CNPP used the cut-point of <4.5g/100g of saturated

Journal Pre-proof

fat (and zero added sugar) to identify higher nutrient density meats and then searched for lower-cost items within each category. Where meat prices varied, further categories were created based on lower or higher national food prices. This was to allow the TFP optimization model to select a market basket of lowest cost protein foods for a nutritious diet.

Identified by the USDA CNPP as higher nutrient density and lower cost meats were numerous cuts of fresh pork: pork chop (baked, broiled, stewed, fried), pork roast, and pork steak/cutlet. Beef liver was listed as well. Lower nutrient density meats (with saturated fat >4.5g/100g) listed in Supplemental data files were pork roast, pork spareribs with barbecue sauce, ground pork, pork steak/cutlet (baked, broiled), and pork chop (breaded and baked, broiled, fried). Also on the list were beef steak (breaded and baked, fried) and beef pot roast.

Similar criteria were used to identify higher nutrient density poultry. Higher nutrient density dairy had no more than 1% fat and zero added sugar. All seafood had high nutrient density.

The higher nutrient density and lower protein foods (n=596) in the TFP 2021 optimization model are shown in **Table 2**. Milk and dairy products, mixed dishes, and grain foods are also shown for comparison. As previously observed, protein content of beef, pork, and poultry was significantly above the other WWEIA categories. The saturated fat content of pork, beef and poultry was significantly lower than for plant proteins (nuts) and egg dishes in the database.

Subsequent modeling analyses conducted by MS-Nutrition (20) replicated CNPP procedures but separated pork from beef to create 5 low-cost healthy food plans. Once pork was an independent modeling category, the TFP algorithm preferentially selected fresh pork. Model 1 replicated the TFP exactly. Models 2 and 3 showed that diets with fresh pork as the only source of meat protein were both healthy and low cost. Model 4 showed that pork could substitute for chicken with no change in nutrient quality and no increase in market basket cost.



Journal Pre-proof

Calculations based on pork as a separate category can help determine the cost of affordable nutrition in the US (38,39). Modeling analyses that replicated the TFP 2021 firmly established pork as a component of practical, healthy, and budget conscious diets that were consistent with US eating habits. Pork (along with chicken) provided the lowest cost way to reach 100% daily value for dietary protein. The versatility of pork meat contributes to its potential as a protein staple in many regional dietary patterns that include vegetables, fruits, whole grains, oils, nuts and seeds.

### 3.3. Pork meat has low greenhouse gas emissions.

Animal proteins have a greater carbon footprint as compared to plant proteins, with most of the calculations pointing to red meat (1,2). However, not all data used to support public policy were context specific or have clearly distinguished among different types of red meat. For example, the very influential paper by Poore and Nemecek (40) was based on a composite of international numbers for 127 countries that did not necessarily reflect the best practices of livestock management in the US. On the other hand, Poore and Nemecek (40) did distinguish between ruminants and non-ruminants and made further useful distinctions between the relative environmental impacts of meat from beef herd, cattle herd, poultry, and pork.

The present analyses used GHGE estimates from previous studies (27,28) on carbon footprint of popular US diets. Protein foods were separated into categories and subcategories and the data were expressed per 50 g of protein. **Figure 4** shows mean GHGE estimates in kg $CO_2$ per 50g of protein. Fresh pork was significantly below beef and lamb, the other red meats, and was closer to eggs, chicken, and beans. One-way ANOVA with post hoc Duncan's test placed pork in the lowest category of GHGE values. It should be noted that the estimated GHGE values for protein from grains and nuts will most likely increase, once PDCAAS values are considered.



Journal Pre-proof

Journal Pre-proof


Treating pork as a separate category may re-shape our ideas about the environmental cost of animal protein, typically measured in terms of GHGE per product weight or volume (kg or L). The present analyses followed the same convention in expressing GHGE per kg of food. A recent FAO report (41) explored the use of alternative nutrition-relevant functional units (nFU) that might better serve nutrition relevant lifecycle analyses (nLCA). One proposal was to base calculations on the amount of protein (DV=50g/day) or on a composite nutrient density score. The carbon footprint of pork could be assessed using 100g of protein as a functional unit (38). Alternatively, the calculations can be based on protein quality (42), or a nutrient density score as proposed by the FAO (41). However, this is a rapidly advancing field, and any calculations ought to be viewed as preliminary and non-definitive.

## 4. The place of pork in the LMIC nutrition transition.

Changes in population diet structure that occur during economic development are commonly referred to as the nutrition transition (43). While the nutrition transition may be primarily income driven, other factors such as urbanization, demographics, and employment also play a role (43,44). Bennett's law (45) is the name given to the observation that richer countries and more affluent consumers abandon root crops and cereals to seek out more varied and more nutrient-dense diets with more vegetables, fruit, and dairy, but especially meat. The proportion of energy from starchy staples, cereals, and potatoes, declines, whereas the proportion of energy from meats increases (45). Effectively, Bennett's Law predicts that plant-based proteins will be replaced by animal proteins as an inevitable consequence of economic growth.

Journal Pre-proof

Laws of economics can serve to predict future global food demand (46,47). In general, richer countries and more affluent consumers will seek out calories that are more expensive and more nutrient rich.

This can be documented by merging FAOSTAT data for energy from plant and animal proteins in calories/capita/day merged with Work Bank incomes for 2019 for the same countries. The present analyses were conducted by GDP deciles and not by World Bank income groups. **Figure 5A** provides yet another confirmation of Bennett's Law showing that the availability of beans, peas, and pulses for human consumption in the 2019 FAO data declines rapidly at higher GDP deciles. **Figure 5B** shows a corresponding increase in the availability of pork, chicken and beef calculated in kg/capita/year. The rapid increase in meat consumption is occurring among middle income countries has also been observed in other studies. There has been an explosive growth in poultry (chicken) consumption, followed by pork (48). By contrast, beef has shown less growth (48,49). While future meat demand can be difficult to predict (50), current OECD models (49) project a 95% increase for animal protein, compared with only 18% for starchy crops. While rising meat consumption across the LMIC is clearly linked to World Bank incomes, other factors can also influence diet structure, including tradition, religion, and culture (51), food prices, and concerns with health and the environment (52).

Journal Pre-proof

It is recent attempts to promote plant-based diets planetary health diets across the LMIC (4,5) that raise some concerns, since they may run counter to the laws of economics and ignore local and territorial preferences and food cultures. For high income countries that may have reached peak meat consumption (53), international agencies and local governments aim to reduce meat consumption to improve diet quality and population health (54). Conversely, agencies and local governments in lower income countries aim to increase meat and dairy consumption, also to

Journal Pre-proof


improve diet quality and population health (55). The present re-analyses of global FAO and World Bank data confirmed that the growing LMIC demand for animal protein was directed mostly toward chicken and pork, rather than beef. It is something of a public health paradox that higher-income countries aim to replace pork with beans, whereas lower-income countries are replacing beans with pork.

It is worth noting that the EAT Lancet proposal to limit meat consumption (5) runs counter to the economic trends and the protein transition that is observed in lower- and middle-income countries (LMIC) (31,33). The growing LMIC demand for animal-sourced foods, mainly meat, is one way to address multiple protein and other nutrient needs (56,57). The traditional and largely plant based LMIC diets are still associated with multiple micronutrient deficiencies. Studies have identified LMIC priority micronutrients as high-quality protein, iron, zinc, calcium, vitamin A, B vitamins, and vitamin D (58). Recent analyses have pointed to shortfalls in the EAT-Lancet planetary health diet for vitamin B12, calcium, iron, and zinc (59). LMIC meat demand is projected to increase substantially over the next decade.

The global dietary shift from plant to animal proteins, previously characterized as a protein transition (44,45), can be viewed as a subset of the broader nutrition transition (43). Although largely income-driven, the protein transition has additional social and cultural components (51). The choice of specific animal proteins (beef, pork, chicken, or dairy) can vary widely depending on geographic region, tradition, religion, or culture. Not all cultures or all religions consume pork.

## 5. Conclusion: The future of pork

Journal Pre-proof

Journal Pre-proof


Livestock systems have long been associated with higher land, water, and energy use and there are fears that they may not be sustainable for much longer (1,2). Health and environmental concerns related to meat production are among the main reasons behind the current initiatives to promote plant proteins on a global scale (5). However, the growth in animal proteins has been in chicken and pork, not beef. We may need to recalibrate our comparisons and pay attention to local contexts and to specific food groups. The present analyses, separating pork from other meats, can help refine the definition of sustainable healthy diets (60).

Pork meat is a source of affordable high-quality protein and may have a lower environmental (GHGE) impact than previously supposed. Separating pork from other red meat may re-shape our ideas about diets and health and the environmental cost of meat production. The present analyses of USDA nutrient composition and national food prices data treated pork as a separate category.  Whereas the amounts of protein in pork, beef, lamb, seafood and chicken were comparable; pork and chicken had the clear price advantage. Achieving affordable nutrient density has been identified by national and international agencies as a priority area (61,62).

The rising LMIC demand for meat protein foods may be hard to stop and harder to reverse, given that it is consistent with Bennett's law. Only a handful of the richest countries have achieved what has been called peak meat consumption (53). The present analyses of FAO data, consistent with many other studies, confirmed that higher country incomes were associated with diets with less starchy staples and more meat, notably chicken and pork.

Journal Pre-proof

ACKNOWLEDGMENTS.

Journal Pre-proof


AD was solely responsible for design, writing, and final content and has read and approved the manuscript. AD has read and approved the final version.

REFERENCES


1. Boehm R, Ver Ploeg M, Wilde PE, Cash SB. Greenhouse gas emissions, total food spending and diet quality by share of household food spending on red meat: results from a nationally representative sample of US households. Public Health Nutr. 2019 Jul;22(10):1794-1806. doi: 10.1017/S136898001800407X. PMID: 30917878; PMCID: PMC10260609.
2. Gaillac R, Marbach S. The carbon footprint of meat and dairy proteins: A practical perspective to guide low carbon footprint dietary choices. J Clean Prod. 2021 Oct 25;321:128766. doi: 10.1016/j.jclepro.2021.128766.
3. Tilman D, Balzer C, Hill J, Befort BL. Global food demand and the sustainable intensification of agriculture. Proc Natl Acad Sci USA. 2011 Dec 13;108(50):20260-4. doi: 10.1073/pnas.1116437108. PMID: 22106295; PMCID: PMC3250154.
4. Eisen MB, Brown PO. Rapid global phaseout of animal agriculture has the potential to stabilize greenhouse gas levels for 30 years and offset 68 percent of CO2 emissions this century. PLOS Clim. 2022 Feb 1;1(2): e0000010. doi: 10.1371/journal.pclm.0000010
5. Willett W, Rockström J, Loken B, Springmann M, Lang T, Vermeulen S et al. Food in the Anthropocene: The EAT-Lancet Commission on healthy diets from sustainable food systems. Lancet. 2019 Feb 2;393(10170):447-492. doi: 10.1016/S0140-6736(18)31788-4. Erratum in: Lancet. 2019 Feb 9;393(10171):530. Erratum in: Lancet. 2019 Jun


Journal Pre-proof

29;393(10191):2590. Erratum in: Lancet. 2020 Feb 1;395(10221):338. Erratum in: Lancet. 2020 Oct 3;396(10256):e56. PMID: 30660336.

6. Gibbs J, Cappuccio FP. Plant-based dietary patterns for human and planetary health. Nutrients. 2022 Apr 13;14(8):1614. doi: 10.3390/nu14081614. PMID: 35458176; PMCID: PMC9024616.

7. Food and Agriculture Organization of the United Nations. Contribution of terrestrial animal source food to healthy diets for improved nutrition and health outcomes: An evidence and policy overview on the state of knowledge and gaps [Internet]. Rome, Italy: FAO; 2023. Available from: http://www.fao.org/documents/card/en/c/cc3912en [Accessed 2024 Feb 20].

8. Food and Agriculture Organization of the United Nations. Meat [Internet]. 2023 [cited 2024 Feb 20]. Available from: https://www.fao.org/markets-and-trade/commodities/meat/en/

9. Datlow LY, Leventhal M, King J, Wallace TC. Consumption patterns and the nutritional contribution of total, processed, fresh, and fresh-lean pork to the U.S. Diet. Nutrients. 2023 Jun 1;15(11):2595. doi: 10.3390/nu15112595. PMID: 37299558; PMCID: PMC10255245.

10. Penkert LP, Li R, Huang J, Gurcan A, Chung MC, Wallace TC. Pork consumption and Its relationship to human nutrition and health: A scoping review. Meat Muscle Biol. 2021 Sept 17;5(1):1-22. doi: 10.22175/mmb.12953.

11. U.S. Department of Agriculture, U.S. Department of Health and Human Services. Dietary Guidelines for Americans 2020-2025 [Internet]. Washington, DC: U.S. Department of

Journal Pre-proof

Journal Pre-proof


Agriculture; 2020 Available from: https://www.dietaryguidelines.gov/sites/default/files/2020-12/Dietary_Guidelines_for_Americans_2020-2025.pdf [Accessed 2024 Feb 20].

12. Bigornia SJ, Noel SE, Porter C, Zhang X, Talegawker SA, Carithers T et al. Red meat consumption, incident CVD and the influence of dietary quality in the Jackson Heart Study. Public Health Nutr. 2022 Jun 23;26(3):1-10. doi: 10.1017/S1368980022001434. PMID: 35733368; PMCID: PMC9989707.

13. Singh B, Khan AA, Anamika F, Munjal R, Munjal J, Jain R. Red meat consumption and its relationship with cardiovascular health: A review of pathophysiology and literature. Cardiol Rev. 2023 Jun 26. doi: 10.1097/CRD.0000000000000575. PMID: 37363999.

14. Zheng Y, Li Y, Satija A, Pan A, Sotos-Prieto M, Rimm E et al. Association of changes in red meat consumption with total and cause specific mortality among US women and men: two prospective cohort studies. BMJ. 2019 Jun 12;365:l2110. doi: 10.1136/bmj.l2110. PMID: 31189526; PMCID: PMC6559336.

15. Mariotti F. Animal and Plant Protein Sources and Cardiometabolic Health. Adv Nutr. 2019 Nov 1;10(Suppl_4):S351-S366. doi: 10.1093/advances/nmy110. PMID: 31728490; PMCID: PMC6855969.

16. Fred Hutch Cancer Center. Nutrition Assessment [Internet]. 2023 [updated 2023 Dec 6; cited 2024 Feb 20]. Available from: https://www.fredhutch.org/en/research/divisions/public-health-sciences-division/research/nutrition-assessment.html

Journal Pre-proof

Journal Pre-proof


17. Agarwal S, Fulgoni VL 3rd. Association of Pork (All Pork, Fresh Pork and Processed Pork) Consumption with Nutrient Intakes and Adequacy in US Children (Age 2-18 Years) and Adults (Age 19+ Years): NHANES 2011-2018 Analysis. Nutrients. 2023 May 13;15(10):2293. doi: 10.3390/nu15102293. PMID: 37242176; PMCID: PMC10221550.

18. U.S. Department of Agriculture, Food and Nutrition Service. Thrifty Food Plan, 2021 [Internet]. Washington, DC: U.S. Department of Agriculture; 2021. Available from: https://fns-prod.azureedge.us/sites/default/files/resource-files/TFP2021.pdf [Accessed 2024 Feb 20].

19. Desilver D, Pew Research Center. What the data says about food stamps in the U.S. [Internet]. 2023 July 19 [cited 2024 Feb 20]. Available from: https://www.pewresearch.org/short-reads/2023/07/19/what-the-data-says-about-food-stamps-in-the-u-s/

20. Poinsot R, Maillot M, Drewnowski A. Fresh pork as protein source in the USDA Thrifty Food Plan 2021: A modeling analysis of lowest-cost healthy diets. Nutrients. 2023 Apr 14;15(8):1897. doi: 10.3390/nu15081897. PMID: 37111116; PMCID: PMC10146423.

21. Drewnowski A, Ecosystem Inception Team. The Chicago Consensus on Sustainable Food Systems Science. Front Nutr. 2018 Apr 25;4:74. doi: 10.3389/fnut.2017.00074. PMID: 29744333; PMCID: PMC5930345.

22. Drewnowski A, Finley J, Hess JM, Ingram J, Miller G, Peters C. Toward Healthy Diets from Sustainable Food Systems. Curr Dev Nutr. 2020 May 20;4(6):nzaa083. doi: 10.1093/cdn/nzaa083. PMID: 32551411; PMCID: PMC7288378.

23. U.S. Department of Agriculture. FoodData Central [Internet]. 2019 [Accessed 2024 Feb 20]. Available from: https://fdc.nal.usda.gov/

24. Rodes DG, Morton S, Martin CL, Adler ME, Hymes MA, Garceau AO et al. USDA Food and Nutrient Database for Dietary Studies 2015-2016 [Internet]. Beltsville, MD: U.S. Department of Agriculture, Agricultural Research Service; 2018. Available from: https://www.ars.usda.gov/ARSUserFiles/80400530/pdf/fndds/FNDDS_2015_2016_factsheet.pdf [Accessed 2024 Feb 20].

25. U.S. Department of Agriculture, Food Surveys Research Group. USDA Food and Nutrient Database for Dietary Studies 2015-2016 [Internet]. Beltsville, MD: U.S. Department of Agriculture, Agricultural Research Service; 2018. Available from: https://www.ars.usda.gov/ARSUserFiles/80400530/pdf/fndds/2015_2016_FNDDS_Doc.pdf [Accessed 2024 Feb 20].

26. U.S. Department of Agriculture. Purchase to Plate [Internet]. 2023 [updated 2024 Jan 25; cited 2024 Feb 20]. Available from: https://www.ers.usda.gov/data-products/purchase-to-plate/

27. Conrad Z, Drewnowski A, Belury MA, Love DC. Greenhouse gas emissions, cost, and diet quality of specific diet patterns in the United States. Am J Clin Nutr. 2023 Jun;117(6):1186-1194. doi: 10.1016/j.ajcnut.2023.04.018. Epub 2023 Apr 17. PMID: 37075848.

28. Conrad Z, Blackstone NT, Roy ED. Healthy diets can create environmental trade-offs, depending on how diet quality is measured. Nutr J. 2020 Oct 27;19(1):117. doi: 10.1186/s12937-020-00629-6. PMID: 33109207; PMCID: PMC7592508.

29. FoodRisk.org. Food Commodity Intake Database [Internet]. 2013 [cited 2024 Feb 20]. Available from: https://fcid.foodrisk.org/

Journal Pre-proof

Journal Pre-proof


30. Food and Agriculture Organization of the United Nations. Livestock Commodities. In: World agriculture: towards 2015/2030 an FAO perspective [Internet]. London: Earthscan publications; 2003. Available from: https://www.fao.org/3/y4252e/y4252e05b.htm [Accessed 2024 Feb 20].

31. Food and Agriculture Organization of the United Nations. Food Balances [Internet]. 2023 [updated 2023 Oct 27; cited 2024 Feb 20]. Available from: https://www.fao.org/faostat/en/#data/FB

32. Grünberger K, Food and Agriculture Organization of the United Nations, Statistics Division. Estimating Food Consumption Patterns by Reconciling Food Balance Sheets and Household Budget Surveys [Internet]. Rome, Italy: FAO; 2014. Available from: http://www.fao.org/3/a-i4315e.pdf [Accessed 2024 Feb 20].

33. The World Bank. World Development Indicators [Internet]. 2021 [updated 2024 Feb 21; cited 2024 Feb 21]. Available from: https://databank.worldbank.org/reports.aspx?source=2&series=NY.GDP.PCAP.CD&country=

34. Hess JM, Cifelli CJ, Agarwal S, Fulgoni VL 3rd. Comparing the cost of essential nutrients from different food sources in the American diet using NHANES 2011-2014. Nutr J. 2019 Nov 9;18(1):68. doi: 10.1186/s12937-019-0496-5. PMID: 31706353; PMCID: PMC6842517.

35. Bekelman TA, Santamaría-Ulloa C, Dufour DL, Marín-Arias L, Dengo AL. Using the protein leverage hypothesis to understand socioeconomic variation in obesity. Am J Hum Biol. 2017 May 6;29(3). doi: 10.1002/ajhb.22953. Epub 2017 Jan 25. PMID: 28121382.

Journal Pre-proof

Journal Pre-proof


36. Schaafsma G. The protein digestibility-corrected amino acid score. J Nutr. 2000 Jul;130(7):1865S-7S. doi: 10.1093/jn/130.7.1865S. PMID: 10867064.

37. U.S. Department of Agriculture, Food and Nutrition Service. Questions and Answers on Alternate Protein Products [Internet]. 2022. [updated 2023 Nov 15; cited 2024 Feb 20]. Available from: https://www.fns.usda.gov/cn/questions-and-answers-alternate-protein-products

38. Drewnowski A, Darmon N, Monsivais P. Affordable Nutrient Density: Toward Economic Indicators of Sustainable Healthy Diets. Sustainability. 2021 Aug 19;13(16):9300. doi: 10.3390/su13169300.

39. Aggarwal A, Drewnowski A. Plant- and animal-protein diets in relation to sociodemographic drivers, quality, and cost: findings from the Seattle Obesity Study. Am J Clin Nutr. 2019 Aug 1;110(2):451-460. doi: 10.1093/ajcn/nqz064. PMID: 31172179; PMCID: PMC6669134.

40. Poore J, Nemecek T. Reducing food's environmental impacts through producers and consumers. Science. 2018 Jun 1;360(6392):987-992. doi: 10.1126/science.aaq0216. Erratum in: Science. 2019 Feb 22;363(6429): PMID: 29853680.

41. Food and Agriculture Organization of the United Nations. Integration of environment and nutrition in life cycle assessment of food Items: opportunities and challenges [Internet]. Rome, Italy: FAO; 2021. Available from: https://www.fao.org/3/cb8054en/cb8054en.pdf [Accessed 2024 Feb 20].

42. McAuliffe GA, Takahashi T, Beal T, Huppertz T, Leroy F, Buttriss J et al. Protein quality as a complementary functional unit in life cycle assessment (LCA). Int J Life Cycle

Journal Pre-proof

Journal Pre-proof


Assess. 2023;28(2):146-155. doi: 10.1007/s11367-022-02123-z. Epub 2022 Dec 28. PMID: 36685326; PMCID: PMC9845161.

43. Drewnowski A, Popkin BM. The nutrition transition: new trends in the global diet. Nutr Rev. 1997 Feb;55(2):31-43. doi: 10.1111/j.1753-4887.1997.tb01593.x. PMID: 9155216.

44. Drewnowski A, Poulain JP. What lies behind the transition from plant-based to animal protein? AMA J Ethics. 2018 Oct 1;20(10):E987-993. doi: 10.1001/amajethics.2018.987. PMID: 30346927.

45. Drewnowski A. Perspective: Alternative proteins in low- and middle-income countries (LMIC) face a questionable future: will technology negate Bennett's law? Curr Dev Nutr. 2023 Sep 1;101994. doi: 10.1016/j.cdnut.2023.101994.

46. Komarek AM, Dunston S, Enahoro D, Godfray HCJ, Herrero M, Mason-D'Croz D et al. Income, consumer preferences, and the future of livestock-derived food demand. Glob Environ Change. 2021 Aug 23;70:102343. doi: 10.1016/j.gloenvcha.2021.102343. PMID: 34857999; PMCID: PMC7612057.

47. Henchion M, Moloney AP, Hyland J, Zimmermann J, McCarthy S. Review: Trends for meat, milk and egg consumption for the next decades and the role played by livestock systems in the global production of proteins. Animal. 2021 Dec;15 Suppl 1:100287. doi: 10.1016/j.animal.2021.100287. Epub 2021 Jul 24. PMID: 34312092.

48. Our World in Data. Animal protein consumption [Internet]. [cited 2024 Feb 20]. Available from: https://ourworldindata.org/grapher/animal-protein-consumption

Journal Pre-proof

Journal Pre-proof


49. Organization for Economic Cooperation and Development, Food and Agriculture Organization of the United Nations. Meat. In: OECD-FAO Agricultural Outlook 2022-2031 [Internet]. Paris: OECD publishing; 2022. doi: 10.1787/ab129327-en.

50. Milford AB, Le Mouël C, Bodirsky BL, Rolinski S. Drivers of meat consumption. Appetite. 2019 Oct 1;141:104313. doi: 10.1016/j.appet.2019.06.005. Epub 2019 Jun 10. PMID: 31195058.

51. Khusun H, Februhartanty J, Anggraini R, Mognard E, Alem Y, Noor M et al. Animal and Plant Protein Food Sources in Indonesia Differ Across Socio-Demographic Groups: Socio-Cultural Research in Protein Transition in Indonesia and Malaysia. Front Nutr. 2022 Feb 11;9:762459. doi: 10.3389/fnut.2022.762459. PMID: 35242792; PMCID: PMC8886573.

52. Bodirsky BL, Rolinski S, Biewald A, Weindl I, Popp A, Lotze-Campen H. Global food demand scenarios for the 21st Century. PLoS One. 2015 Nov 4;10(11):e0139201. doi: 10.1371/journal.pone.0139201. PMID: 26536124; PMCID: PMC4633131.

53. Whitton C, Bogueva D, Marinova D, Phillips CJC. Are we approaching peak meat consumption? Analysis of meat consumption from 2000 to 2019 in 35 countries and its relationship to gross domestic product. Animals (Basel). 2021 Dec 6;11(12):3466. doi: 10.3390/ani11123466. PMID: 34944243; PMCID: PMC8697883.

54. Safe Food Advocacy Europe. Actions and policies related to reduction in the consumption of meat in four countries: UK, France, Germany and Switzerland. [Internet]. Brussels, Belgium: SAFE; 2020. Available from: https://www.safefoodadvocacy.eu/wp-content/uploads/2023/03/SAFE_LessBetterMeat_WorkDoc_June2020_final.pdf [Accessed 2024 Feb 20].

Journal Pre-proof


55. Food and Agriculture Organization of the United Nations, Animal Production and Health Division. Poultry Development Review [Internet]. Rome, Italy: FAO; 2013. Available from: https://www.fao.org/3/i3531e/i3531e.pdf [Accessed 2024 Feb 20].

56. Beal T, Gardner CD, Herrero M, Iannotti LL, Merbold L, Nordhagen S et al. Friend or Foe? The Role of Animal-Source Foods in Healthy and Environmentally Sustainable Diets. J Nutr. 2023 Feb;153(2):409-425. doi: 10.1016/j.tjnut.2022.10.016. Epub 2023 Jan 19. PMID: 36894234.

57. Stevens GA, Beal T, Mbuya MNN, Luo H, Neufeld LM. Global Micronutrient Deficiencies Research Group. Micronutrient deficiencies among preschool-aged children and women of reproductive age worldwide: a pooled analysis of individual-level data from population-representative surveys. Lancet Glob Health. 2022 Nov;10(11):e1590-e1599. doi: 10.1016/S2214-109X(22)00367-9. PMID: 36240826.

58. Beal T, Ortenzi F. Priority micronutrient density in foods. Front Nutr. 2022 Mar 7;9:806566. doi: 10.3389/fnut.2022.806566.

59. Beal T, Ortenzi F, Fanzo J. Estimated micronutrient shortfalls of the EAT-Lancet planetary health diet. Lancet Planet Health. 2023 Mar;7(3):e233-e237. doi: 10.1016/S2542-5196(23)00006-2.

60. Food and Agriculture Organization of the United Nations, World Health Organization. Sustainable healthy diets: Guiding principles. Rome, Italy: FAO; 2019. Available from: http://www.fao.org/3/ca6640en/ca6640en.pdf [Accessed 2024 Feb 20].

61. Food and Agriculture Organization of the United Nations, International Fund for Agricultural Development, United Nations International Children's Emergency Fund, World Food Programme, World Health Organization. The State of Food Security and

Journal Pre-proof

Nutrition in the World 2020 [Internet]. Rome, Italy: FAO; 2017. Available from: https://www.fao.org/3/ca9692en/online/ca9692en.html [Accessed 2024 Feb 20].

62. Herforth A, Bai Y, Venkat A, Mahrt K, Ebel A, Masters WA. Cost and affordability of healthy diets across and within countries: Background paper for The State of Food Security and Nutrition in the World 2020. FAO Agricultural Development Economics Technical Study No. 9 [Internet]. Rome, Italy: FAO; 2020. Available from: https://www.fao.org/documents/card/en/c/cb2431en/5 [Accessed 2024 Feb 20].

Journal Pre-proof

Journal Pre-proof


Table 1: Protein content (g/100g), energy density (kcal/100g) and estimated kcal needed to obtain 50g of protein by food group and category in the Food and Nutrient Database for Dietary Studies.

| | | Protein content g/100g | | Energy density kcal/100g | | Kcal for 50g (100%DV*) of protein | |
|---|---|---|---|---|---|---|---|
| Food category | N | Protein g/100g | SEM* | Mean | SEM | Kcal | SEM |
| Beef | 81 | 27.27 | 0.45 | 228.75 | 6.04 | 441.47 | 20.96 |
| Pork | 83 | 25.39 | 0.64 | 247.66 | 8.81 | 535.16 | 50.05 |
| Lamb | 23 | 25.22 | 0.49 | 245.30 | 14.53 | 496.28 | 35.18 |
| Cured meats | 46 | 23.96 | 1.18 | 284.85 | 21.29 | 869.96 | 293.79 |
| Poultry | 224 | 23.18 | 0.28 | 214.38 | 3.50 | 496.45 | 14.32 |
| Seafood | 434 | 21.01 | 0.35 | 177.13 | 2.73 | 447.96 | 8.51 |
| Animal Protein | 109 | 19.53 | 0.7 | 229.88 | 8.39 | 693.84 | 38.10 |
| Plant Protein | 174 | 13.71 | 0.58 | 361.96 | 15.92 | 2365.15 | 900.69 |
| Eggs | 151 | 11.84 | 0.17 | 169.20 | 4.52 | 712.13 | 15.15 |
| Mixed Dishes | 1985 | 8.92 | 0.11 | 172.18 | 1.87 | 1152.25 | 14.87 |
| Milk and Dairy | 239 | 8.76 | 0.57 | 135.19 | 7.67 | 1181.44 | 94.19 |
| Grains | 624 | 6.84 | 0.14 | 253.81 | 4.35 | 2250.26 | 169.01 |

SEM standard error of the mean. DV daily value

Journal Pre-proof

Journal Pre-proof


Table 2: Nutrient content of foods identified as higher nutrient density in the Thrifty Food Plan 2021 (N=596)

| Food category | N | Protein g/100g | SEM | Saturated fat g/100g | SEM | Sodium | SEM | Potassium | SEM |
|---|---|---|---|---|---|---|---|---|---|
| Beef | 15 | 28.72a | 0.54 | 2.65a | 0.19 | 382a | 8 | 328a | 15 |
| Pork | 16 | 27.58a | 0.37 | 2.41a | 0.22 | 511a | 16 | 437a | 16 |
| Poultry | 90 | 23.62a | 0.45 | 2.36a | 0.11 | 425a | 11 | 269 | 5 |
| Plant proteins | 54 | 17.04 | 0.92 | 6.67 | 0.59 | 167 | 26 | 605 | 26 |
| Eggs | 17 | 11.47 | 0.30 | 4.53 | 0.30 | 307 | 16 | 151 | 6 |
| Mixed dishes | 294 | 7.65 | 0.24 | 2.22 | 0.12 | 305 | 7 | 179 | 4 |
| Milk and dairy | 31 | 4.73 | 0.43 | 1.28 | 0.21 | 64 | 6 | 183 | 10 |
| Grains | 75 | 7.73 | 0.45 | 0.92 | 0.12 | 349 | 25 | 233 | 17 |

SEM Standard error of the mean

Journal Pre-proof

Journal Pre-proof


**FIGURE CAPTIONS**

**Figure 1**. A scatterplot of mean grams of protein/100g (A) and percent daily value (%DV) for protein (B) plotted against mean energy density (kcal/100g) for protein foods, milk and dairy in the FNDDS 2015-16 database. Size of the bubble corresponds to the number of food items in each category. FNDDS Food and Nutrient Database for Dietary Studies. USDA US Department of Agriculture.

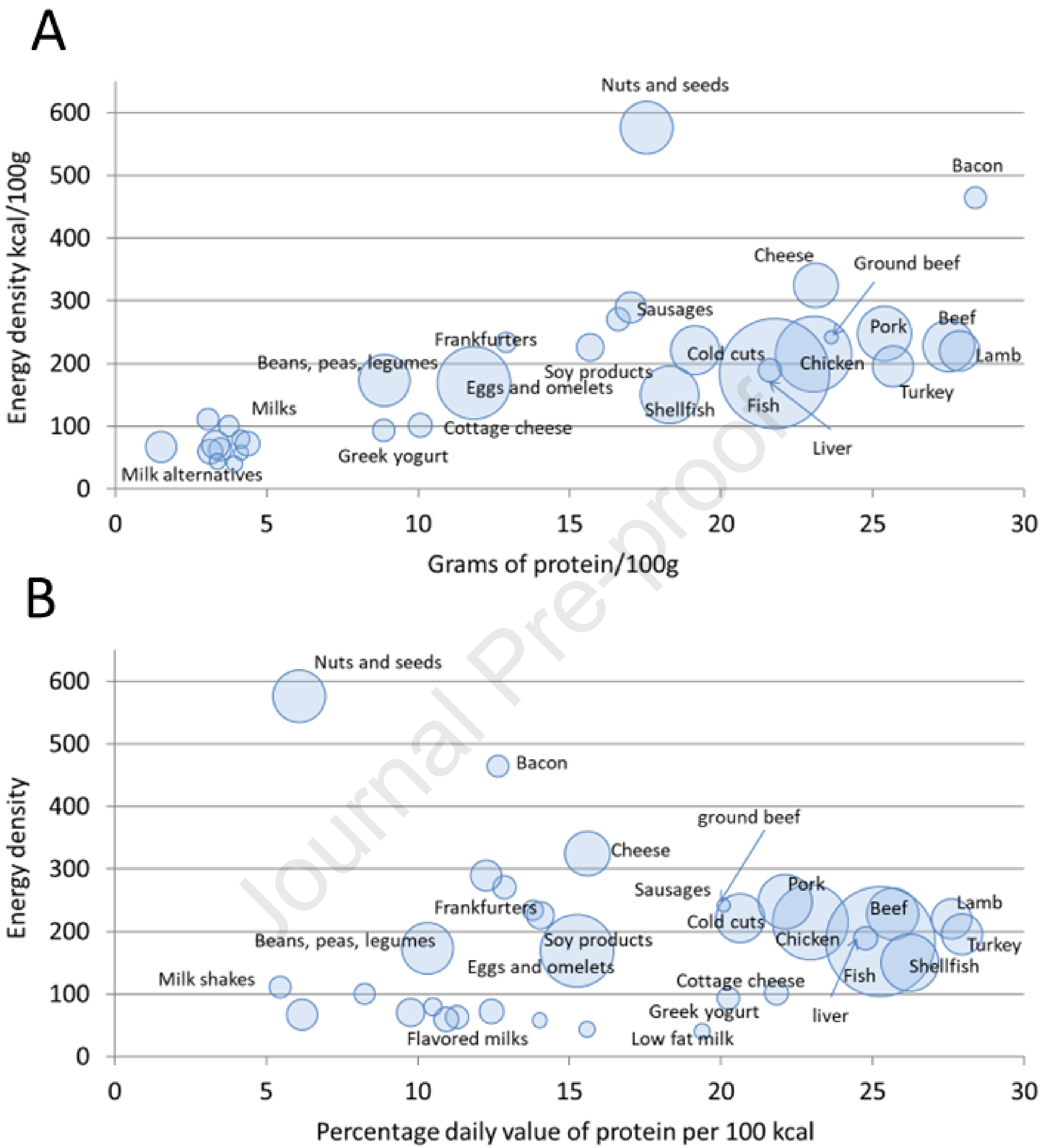
**Figure 2** Scatterplot of mean price per 100 g ($/100g) plotted against mean energy density (kcal/100g) of protein foods, milk and dairy in the FNDDS 2015-16. Size of the bubble corresponds to the number of food items in each category. FNDDS Food and Nutrient Database for Dietary Studies. USDA US Department of Agriculture.

**Figure 3**: Monetary cost in US dollars per 50 g of protein (100%DV) shown in decreasing order. National prices are from the USDA 2021 Thrifty Food plan.

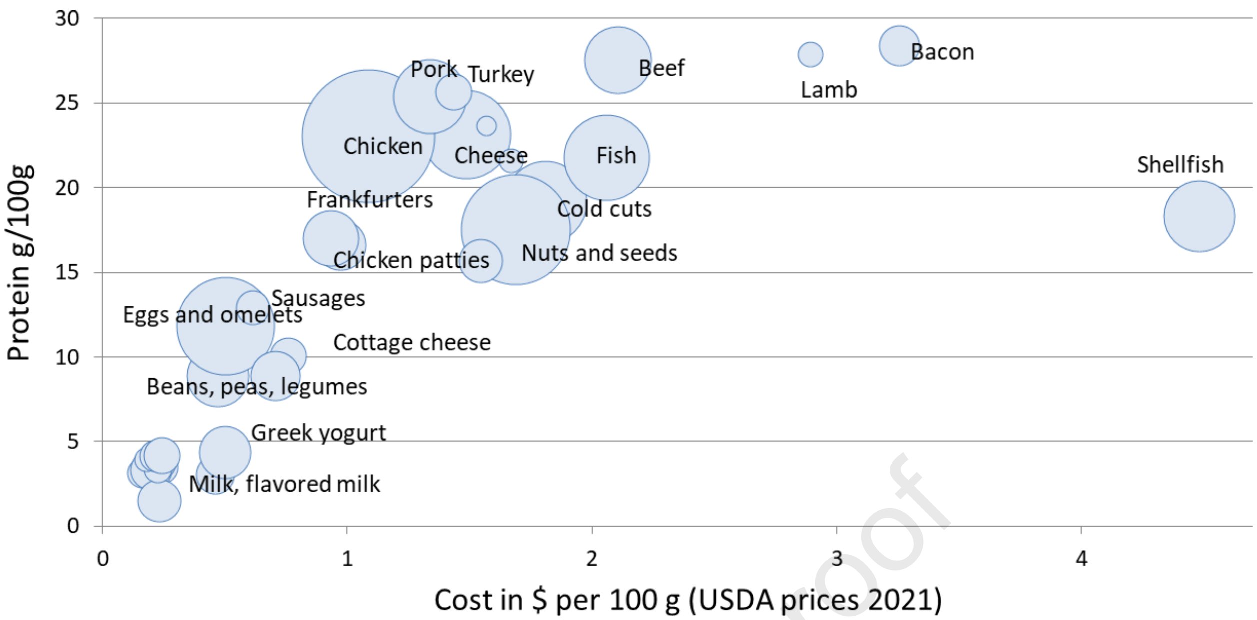
**Figure 4.** Estimated mean greenhouse gas emissions (GHGE) in CO2 eq kg per 50g of protein (100%DV) plotted against mean protein content of foods in g/100g by category. CO2 eq. carbon dioxide equivalents.

**Figure 5.** The relation between beef, pork and chicken (A) and pulses, peas and beans (B) available for human consumption in 2019 by deciles of GDP per capita by country. Food balance sheets from Food and Agriculture Organization of the United Nations. GDP data from the World Bank. GDP Gross Domestic Product.

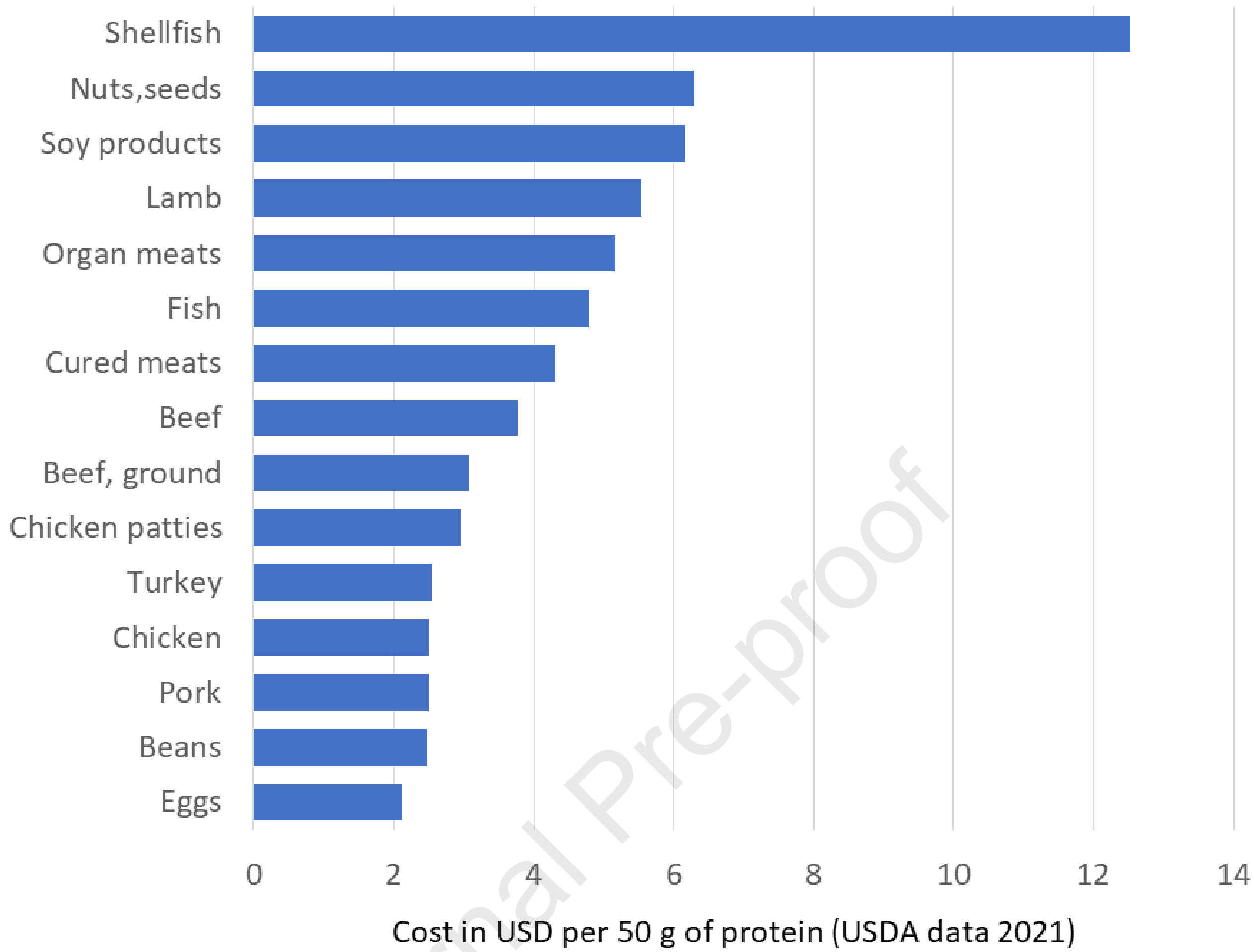
Journal Pre-proof



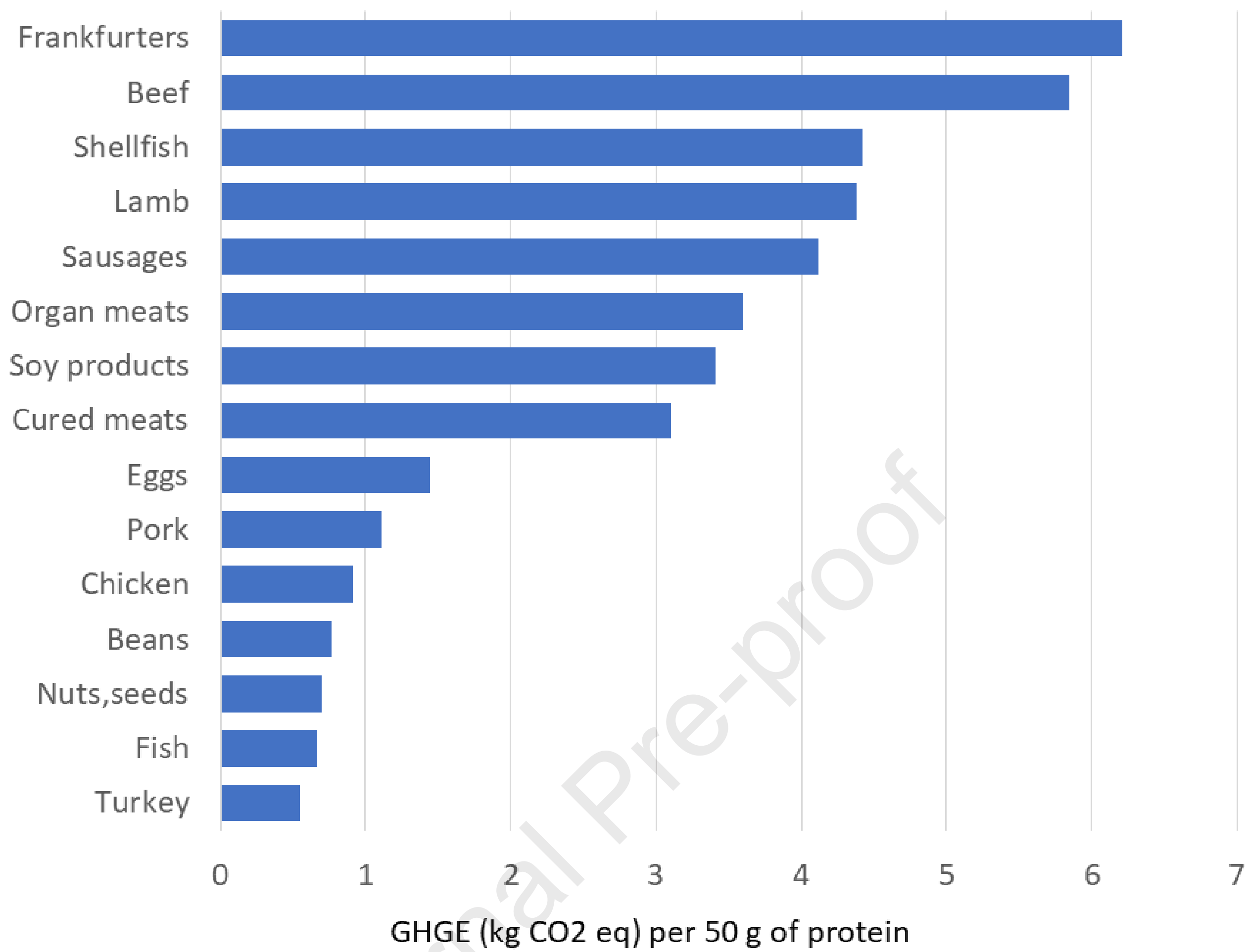

Journal Pre-proof




Journal Pre-proof

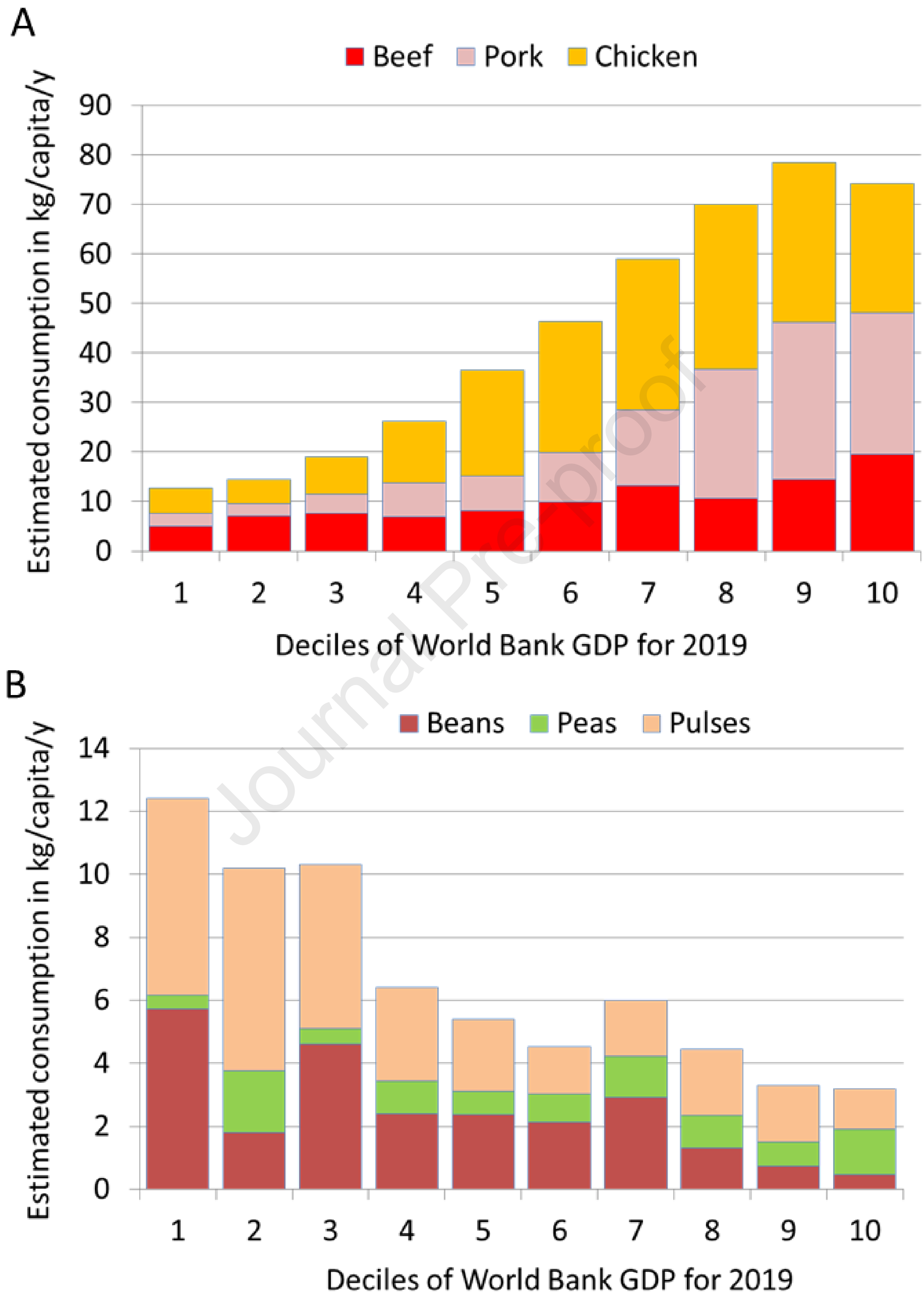



Journal Pre-proof




Journal Pre-proof

Journal Pre-proof
Journal Pre-proof




Journal Pre-proof

Journal Pre-proof

Journal Pre-proof

Journal Pre-proof

**Declaration of interests**

☐ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☒ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Adam Drewnowski reports financial support was provided by National Pork Board. Adam Drewnowski reports a relationship with National Pork Board that includes: consulting or advisory. AD is the original developer of the Naturally Nutrient Rich (NNR) and the Nutrient Rich Food (NRF) nutrient profiling models. AD is a member of scientific advisory panels for National Pork Board, Nestlé, FrieslandCampina, BEL, and Carbohydrate Quality Panel supported by Potatoes USA and has worked with Ajinomoto, FoodMinds, KraftHeinz, Nutrition Impact LLC, Nutrition Institute, PepsiCo, and Samsung on quantitative ways to assess nutrient density of foods. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Journal Pre-proof