Meat Me for Supper? Envisioning the Future of Protein Food

by

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Abstract

This report investigates future challenges associated with protein food and explores two proposed mitigation strategies for overcoming them: dietary change and cultivated meat. Utilizing IMPACT, this report assesses the food security dimensions of availability and economic access for protein food relative to the EAT-Lancet recommendations, projected to 2050, under various shared socioeconomic pathways. This work reveals a near universal over-supply of red meat as well as an under-supply in plant protein across UN member states, even as animal sources of protein far exceed their plant counterparts on a price per kilocalorie basis. Additionally, this report conducts a high level SWOT analysis of key issues in cultivated meat, finding that the technology platform could deliver meaningful environmental and health benefits, but without overcoming important technical and political barriers, will remain unavailable and inaccessible for the foreseeable future. Together, these findings offer insights for food and agricultural policymakers interested in planning and preparing for protein-related issues in the next quarter-century. This report concludes with policy recommendations, intended primarily for the United States.

Acknowledgments

To Frank, Barb, and Elena for
facilitating dreams that once seemed well out of reach.

To Ken and Greg for
believing in my potential and encouraging my growth.

To Myron and Ioannis for
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To Amelia for
unwavering support, enduring hope, comforting nights, and nourishing meals.

To my Old Kentucky Home for
engendering a zeal for the natural world.

In memoriam, Heikki and Larry.

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Purpose and Guiding Questions

As humanity continues to grow, our nutritional needs imperil an already strained planet. This report aims to better understand challenges for protein food on Earth (and beyond) in the coming decades, from both a technical and policy perspective. Its ultimate goal, should one exist, is to serve as a starting point for consideration and conversation concerning the future of protein food production and consumption.

In pursuit of this, it addresses several questions over three core sections:

1. Why is protein food, in particular, important to address?
2. What are some options for mitigating challenges associated with protein food?
3. How does the proposal of dietary change look through a food security lens?
4. Can an innovation like cultivated meat succeed where other proposals appear to fail?

Figure 1: Early Art of Humans Hunting (Nowell, 2022)

"Tell me what you eat: I will tell you what you are."

Jean Anthelme Brillat-Savarin, 1825 (2019)

Background

Significance of Protein

Proteins, from the Greek, *πρωτεῖος*, meaning first quality, perform an astonishing array of biological functions (Oxford English Dictionary, 2023b). Many act as catalysts, facilitating myriad chemical reactions in cells, for example, glycolysis, the breaking down of glucose for energy extraction, a metabolic pathway that involves ten mediating enzymes (Li et al., 2015). Other proteins carry out structural responsibilities, like collagen, which constitutes a primary component of connective tissue, or elastin, which confers the requisite stretchiness to organs such as the lungs and the aorta (Numata, 2020; Halper, 2014; Karsdal et al. 2016).

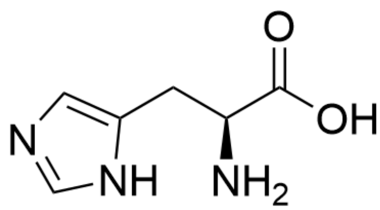
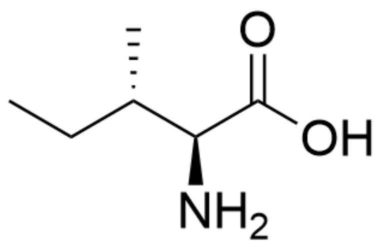
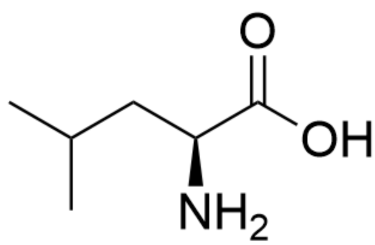
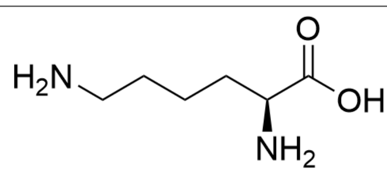
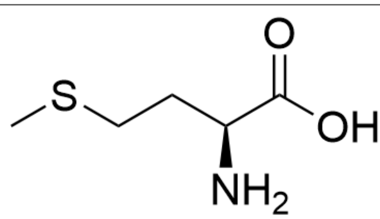
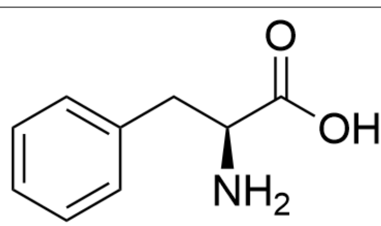
In some cases, proteins regulate and actively maintain bodily activities. Take for example p53, which protects against genomic mutation and hinders tumorigenesis (Niazi et al., 2018). To mitigate disease caused by alien pathogens, B cells produce antibodies, or immunoglobulin, a type of defensive protein capable of binding to and neutralizing infectious agents like viruses and bacteria (James, 2022). Hemoglobin exemplifies a carrier protein, responsible for transporting oxygen from the lungs to the tissues as well as carbon dioxide waste in the reverse direction (Marengo-Rowe, 2006). Sensory proteins like opsins, present in the cone cells of the retina, permit the sensation of color vision (Imamoto & Shichida, 2014). In most eukaryotes, including humans, motor proteins, like myosin II, allow locomotion and other movement via muscular contraction (Shutova & Svitkina, 2018). Finally, proteins may also serve as stores of vital nutritional resources, as seen with whey and casein in human milk (Donovan et al., 2019).

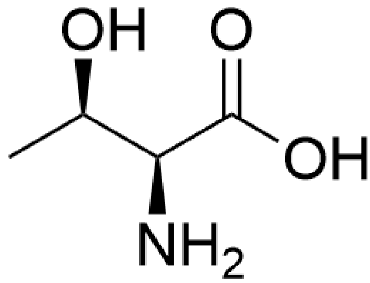
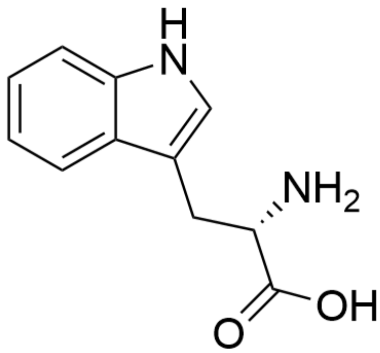
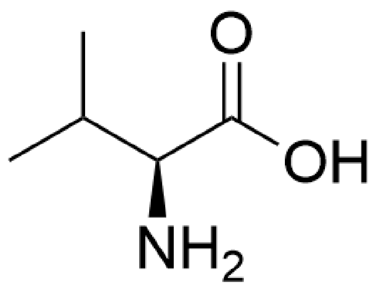
Scientific opinions vary on the exact size of the human proteome depending on criteria used to determine distinctness of a given protein, with estimates extending from approximately twenty thousand, if proteins are definitionally tied to genes, to well over one billion, if immunological variants count as individual proteins (Aebersold et al., 2018). Despite the sheer diversity suggested by even the conservative position, at the most rudimentary level of organization, the primary structure of all proteins consists of a chain of amino acids (AAs), linked together by peptide bonds (Buxbaum, 2015). Interestingly, in humans, just twenty AAs are needed to yield the vast range of protein forms and functions only briefly described here (Li et al., 2021).

This relatively small set of proteinogenic AAs is commonly partitioned into three categories according to the human body's method of acquiring them for the purpose of protein construction. Indispensable or essential AAs (EAAs) cannot be produced de novo and must originate in the diet (Li et al., 2021). Conversely, dispensable or non-essential AAs can be synthesized by the body using other extant AAs or nitrogen-containing compounds (Li et al., 2021). Lastly, conditionally indispensable AAs may be manufactured by the body, but not necessarily at levels required to meet metabolic needs (Li et al., 2021).

Table 1 lists the names (with both three and one letter codes in parentheses), the skeletal formulae, and the SMILES notation for the nine EAAs for humans, which can only be obtained through dietary consumption (Li et al., 2021; National Center for Biotechnology Information, 2024).

Table 1: Nine Essential Amino Acids for Humans

Amino Acid	Skeletal Formula	SMILES (isometric)
Histidine (His, H)		C1=C(NC=N1)C[C@@H](C(=O)O)N
Isoleucine (Ile, I)		CC[C@H]©[C@@H](C(=O)O)N
Leucine (Leu, L)		CC©C[C@@H](C(=O)O)N
Lysine (Lys, K)		C(CCN)C[C@@H](C(=O)O)N
Methionine (Met, M)		CSCC[C@@H](C(=O)O)N
Phenylalanine (Phe, F)		C1=CC=C(C=C1)C[C@@H](C(=O)O)N

Threonine (Thr, T)		C[C@H]([C@@H](C(=O)O)N)O
Tryptophan (Trp, W)		C1=CC=C2C(=C1)C(=CN2)C[C@@H](C(=O)O)N
Valine (Val, V)		CC©[C@@H](C(=O)O)N
Source: National Center for Biotechnology Information (2024)		

Because EAAs must come from food, in order to construct all of the proteins consistent with healthy bodily function, humans must intake foods whose proteins contain sufficient quantities of all nine EAAs, which are extracted through digestion (Li et al., 2021). Many foods supply protein, and therefore polypeptide chains of various AAs, but the identities and concentrations of those AAs differ across foods (Li et al., 2021). Wheat, for instance, contains a meaningful amount of dietary protein but remains an incomplete source of EAAs due to its limited supply of lysine (Li et al., 2021; Davies & Jakeman, 2020).

This means that the consideration of protein quality, which concerns the digestibility and profile of EAAs, should accompany consideration of basic protein content for a given food when determining its potential benefit to nutrition (Li et al., 2021; Davies & Jakeman, 2020). A person fully dependent on wheat for supplying his or her protein could, in theory, have a high protein intake in terms of quantity but still suffer a major dietary deficiency with respect to protein quality (Li et al., 2021; Davies & Jakeman, 2020). Though criticized as a potentially “misleading” concept in the scientific literature, in more public-facing publications it is common to classify single food items that more optimally supply all nine EAAs as ‘complete,’ while those that do not as 'incomplete' (Mariotti & Gardner, 2019; Paddon-Jones et al., 2017; Cleveland Clinic, 2022). Because this report is concerned with protein food from a policy-oriented perspective, it preserves this taxonomy under the assumption that it is familiar, accessible, and meaningful to the general public.

Accordingly, animal source foods (ASFs) play a pivotal role in human diets across the globe by virtue of their robust EAA profiles. ASFs such as red meat, fish, poultry, eggs, and dairy are complete proteins, and thus as individual foods, conveniently require no complement to supply consumers the nine EAAs (Cleveland Clinic, 2022; Paddon-Jones et al., 2017). Likewise, soybeans qualify as a complete protein (Cleveland Clinic, 2022). This contrasts with several other plant-derived sources of protein, namely non-soy legumes and tree nuts, commonly championed for their beneficial, albeit incomplete, EAA profiles (Cleveland Clinic, 2022). This, however, does not invalidate the non-soy plant protein foods as meaningful providers of EAAs, as they can satisfy nutritional needs when sufficiently combined with one another as well as other plant-based foods, like wheat, in the diet (Mariotti & Gardner, 2019).

The significance of these protein-rich foods, of both animal and plant origin, are well reflected throughout national food-based dietary guidelines (FBDGs) (Herforth et al., 2022). Table 2 lists ten example FBDGs and their recommendations (daily) for protein-rich foods, adapted from a table provided by Herforth et al. (2022):

Table 2: Protein-Rich Food Recommendations in Food-Based Dietary Guidelines

FBDGs	kCal	grams	Protein-Rich Food Subcategories
Argentina	638	446	meat, fish, egg, dairy
Benin	462	323	meat, fish, egg, legumes, nuts and seeds, dairy
China	568	398	meat, fish, egg, dairy, soy, nuts, seeds
India	809	566	meat, fish, egg, legumes, nuts and seeds, dairy
Jamaica	630	441	foods from animals including dairy, legumes and nuts
Malta	572	400	meat, fish, eggs, legumes, nuts and seeds, dairy
Netherlands	577	404	meat, fish, egg, legumes, nuts and seeds, dairy
Oman	335	234	meat, fish, egg, nuts and seeds, legumes, dairy
United States	753	527	meat, fish, egg, legumes, nuts and seeds, dairy
Viet Nam	640	447	meat, fish, egg, legumes, dairy

Source: Herforth et al. (2022)

Countries commonly represent their FBDGs in the form of simplified and approachable graphics for the public. Figure 2 (USDA, n.d.) and Figure 3 (FAO, n.d.) are two examples of these visualizations, both of which unequivocally convey the perceived national importance of protein-rich foods in general and ASFs in particular.

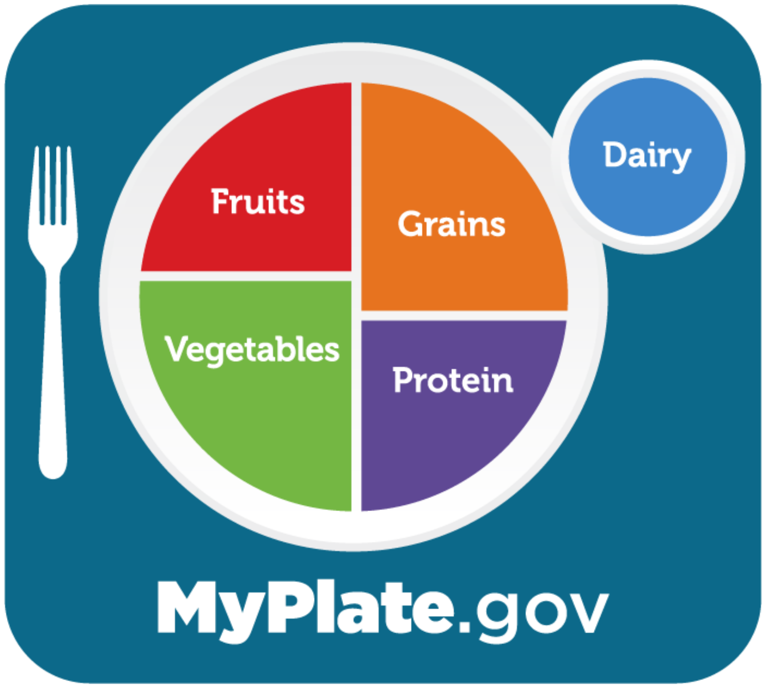


Figure 2: MyPlate from the United States

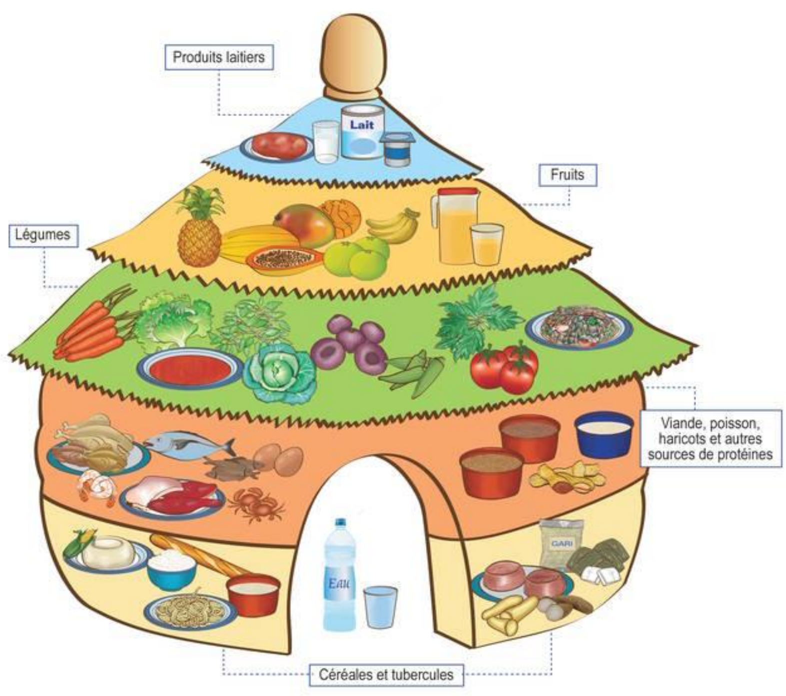
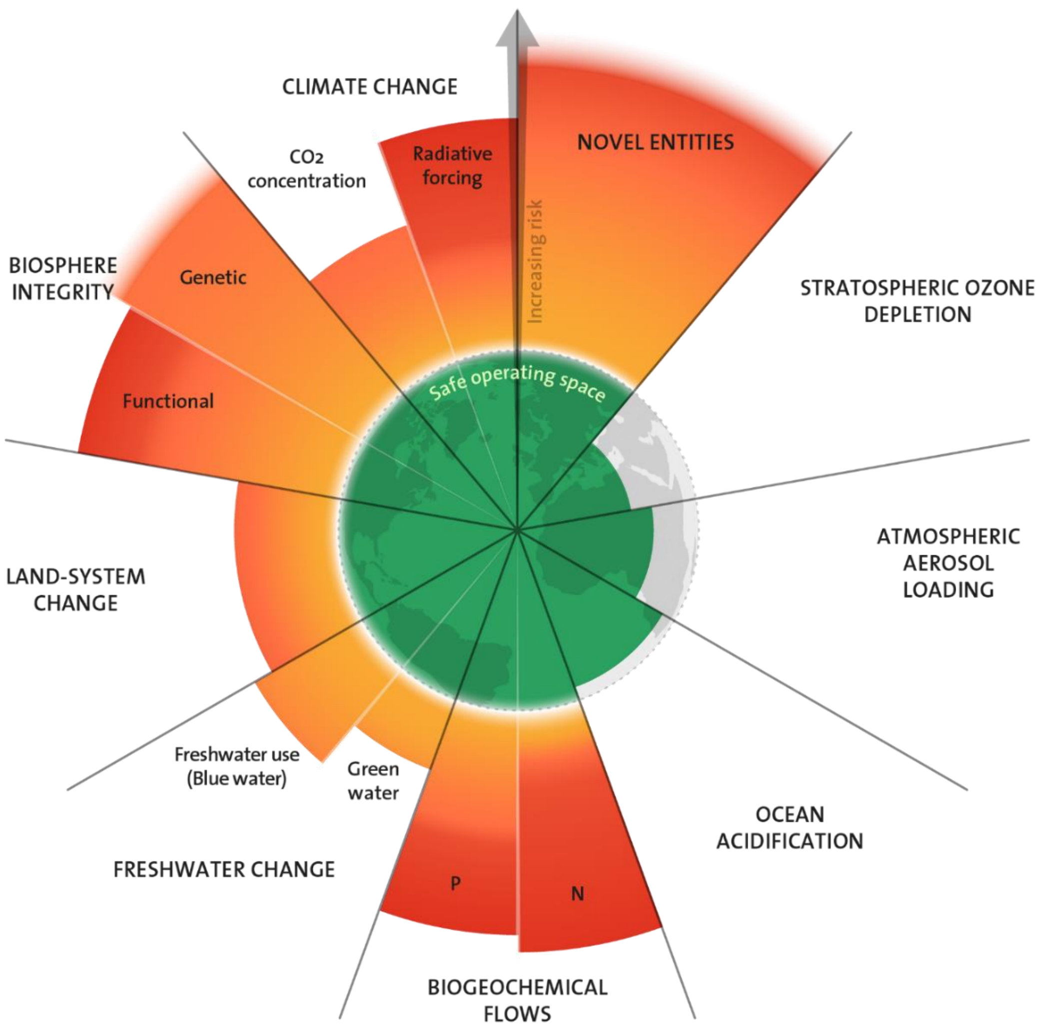


Figure 3: Benin's FBDGs in the Form of a House

Using averages from the ten FBDGs tabulated above, Herforth et al. (2022) generated the Healthy Diet Basket (HDB) to serve as "a global standard of a healthy diet consistent with and reflective of the commonalities in dietary guidelines across countries." Alongside other typical food groups such as starchy staples and fruit, the HDB codifies ASFs and plant proteins (legumes, nuts, and seeds) as calorically coequal components of a healthy diet (Herforth et al., 2022).

Figure 4: Status of the Planetary Boundaries



(Credit: Azote for Stockholm Resilience Centre, 2023; Richardson et al., 2023)

However, despite their significance to diets worldwide, contemporary patterns of ASF production and consumption bear implications far wider than nutritional outcomes. Under the planetary boundaries framework, as of 2023, humanity already exceeds safe operating spaces[1] for all five of the nine planetary boundaries deemed relevant to food systems (visualized in Figure 4), which include biogeochemical flows (nitrogen and phosphorus cycles), freshwater change, land system change, biosphere integrity, and climate change (Richardson et al., 2023; Willett et al., 2019). Through a host of interconnected, negative externalities, conventional ASF systems contribute disproportionately to these strains while generating distinct public health risks, which together threaten environmental, economic, and social sustainability on a global scale.

Environmental and Health Impacts of Animal Source Food Production

Today's animal agricultural systems exert an enormous strain on the environment and its natural resources. Humanity has dedicated as much as half of all habitable land on Earth to farmland, with over three quarters of that set aside for livestock or their feed (Ritchie & Roser, 2019). Other crops, such as wheat or corn for human consumption, only occupy about 16 percent of all agricultural lands (Ritchie & Roser, 2019). Producing a single kilogram of either pork, mutton, or beef, requires inputs of 6.4, 15, or 25 kilograms of feed, with protein conversion efficiencies of only 8.5, 6.3, or 3.8 percent, respectively (Alexander et al., 2016). This demand for land drives extensive deforestation, clearing up to five million hectares of primarily tropical forest each year, which in turn contributes to biodiversity loss (Ritchie, 2021; Barlow et al., 2016). Beef alone accounts for 41% of these land clearings (Ritchie, 2021).

In addition to land, just the feed for raising livestock consumes a staggering 4,387 cubic kilometers of water each year, or about four-tenths of all agricultural water (Heinke et al., 2020). This colossal allocation of natural resources to livestock has led to a shocking consolidation of the world's biomass. Presently, non-human livestock constitute over 95 percent of mammalian and 70 percent of avian biomass on Earth (Bar-On et al., 2018).

Supporting such massive livestock populations contributes significantly to climate change through greenhouse gas (GHG) emissions. In fact, the sum of all food production results in at least 26 percent of global GHG emissions, where a majority of that figure, approximately 15 percent, comes directly from ASF production (Poore & Nemecek, 2018a). Once more, beef stands out as perhaps the worst offender in terms of environmental impact among agricultural commodities, emitting the most GHGs by far at over 4,000 Tg CO_2-eq, compared with rice at just over 2,000 Tg CO_2-eq, the second worst emitter (Xu et al., 2021).

Beyond harm to the environment, animal agriculture also creates serious health and security concerns by way of zoonotic disease risk. Over the last half-century, more than 70 percent of emerging infectious diseases have been found to spread from contact with animals (Wang &

[1] "The planetary boundaries framework formulates limits to the impact of the anthroposphere on Earth system by identifying a scientifically based safe operating space for humanity that can safeguard both Earth's interglacial state and its resilience" (Richardson et al., 2023)

Crameri, 2014; Marchese & Hovorka, 2022). And unfortunately, the conditions of modern factory farms provide an ideal context for the future proliferation of zoonoses (Marchese & Hovorka, 2022).

Facilities often boast thousands of animals in highly cramped, minimally ventilated conditions that ease the flow of pathogens across individuals (Marchese & Hovorka, 2022). Making matters worse, overuse or misuse of antibiotics remains common, contributing to antibacterial resistance (Marchese & Hovorka, 2022). Moreover, when multiple types of livestock cohabitate within a single facility, such as cattle and swine, pathogens may undergo selective pressure for adaptations that facilitate crossing the species barrier (Marchese & Hovorka, 2022). This may also occur during times of transport in or out of factory farms, as livestock encounter wildlife and their pathogens under unnatural circumstances (Marchese & Hovorka, 2022). Thus, when human workers interact with these livestock, at any stage of meat production, they face the risk of contracting illness from a potentially vast array of viral and bacterial pathogens, known and unknown to the scientific community, which may then spread throughout the world without warning (Marchese & Hovorka, 2022).

Prion diseases typify another, disconcerting possibility of today's meat production. Universally lethal, untreatable, and transmissible through diet, these neurodegenerative conditions result from misfolded, self-replicating proteins accumulating in the central nervous system (Watson et al., 2021). Variant Creutzfeldt-Jakob disease (vCJD), the human equivalent of bovine spongiform encephalopathy (BSE) or mad cow, manifests following consumption of beef tissues, particularly those of the nervous system, that are infected with prions (Watson et al., 2021). A notable outbreak in the United Kingdom, which peaked in 2000, has claimed at least 178 lives (National CJD Research & Surveillance Unit, 2022).

Watson et al. (2021) warn that, despite mitigations which have decreased the global burden of vCJD since that outbreak, emerging animal prion diseases such as chronic wasting disease discovered in North American, European, and Korean deer, justify continued vigilance. In the US, wild deer are commonly hunted and consumed, posing a risk of exposure (Watson et al., 2021). However, direct consumption of deer may not be necessary to reach humans with time. The leading hypothesis for the origin of BSE is the contamination of cattle feed with "material from a scrapie-infected sheep" (Watson et al., 2021). Scrapie, a prion disease, infected beef cattle and eventually induced vCJD in humans, possibly as a result of using meat-and-bone meal (an animal byproduct) as feed for cattle (Watson et al., 2021).

Commercial fishing operations likewise exact a substantial environmental toll. According to the Food and Agriculture Organization (FAO) of the United Nations (UN), fish and seafood supply over three billion people with nearly a fifth of their animal source protein (FAO, 2022). Despite this significance, current practices have left many fisheries overexploited. Over the last five decades, as global demand for seafood has quadrupled, the proportion of fish caught from biologically sustainable stocks plunged from 90 to 64.6 percent (FAO, 2022).

Beyond direct depletion, certain methods employed by fishing fleets can cause additional harm. Bottom trawling, a common method of commercial fishing, involves vessels dragging heavy, cone-shaped nets on or just above the seabed, which disrupt natural habitats and may release as many GHGs as aviation, if not more (Sala et al., 2021; Einhorn, 2021). High demand for seafood has also fueled illegal, unreported, and unregulated (IUU) fishing behavior which exacerbates these issues by evading existing and, theoretically, future regulatory mechanisms intended to safeguard sea life and their biomes (Liddick, 2014; FAO, 2022).

In recent decades, aquaculture has exploded in popularity as an alternative to capture-based fisheries. Aquaculture, the act of farming seafood animals as livestock in controlled environments, surpassed traditional fishing by 2013 in terms of the volume of seafood produced worldwide and continues to grow at a rapid pace (Ritchie, 2019). Although techniques associated with aquaculture avoid several of the deleterious shortcomings of commercial fishing, a major concern is that it inherits similar disease-related challenges from farming on land, as thousands of aquatic livestock crowd together, usually in net pens or sea cages staged within natural environments (Bouwmeester et al., 2021). However, unlike farming on land, aquaculture presents disease risk largely to natural animal populations that exist just outside of the livestock's permeable enclosures (Bouwmeester et al., 2021).

Future Mitigation

Without intervention, for the foreseeable future, ASF production systems will continue to engender and operate under considerable pressures. According to the latest projections from the UN, the world population could reach as high as 8.5 billion by 2030 and approach 10 billion by mid-century (United Nations Department of Economic and Social Affairs, 2022). Continued growth means more mouths to feed, a task complicated by an already unsustainable relationship with Earth's resources (Figure 4).

Moreover, the world is growing richer, and as incomes rise, so does the demand for resource-intensive, ASF products like red meat (Milford et al., 2019; Fukase & Martin, 2020). Simply expanding ASF production to meet this rising demand without steps to confront the current extent of environmental and social impact may exacerbate existing threats and further risk the precarious foundation on which the entirety of the global food system currently rests.

Given the rising demand for protein, how can societies across the world hope to curb the pernicious effects of their production without sacrificing the public's nutritional needs?

In 2015, member states of the UN adopted the 2030 Agenda for Sustainable Development, which established seventeen Sustainable Development Goals (SDGs) addressing key, integrated issues across economic, environmental, and social spheres (United Nations General Assembly, 2015). From this set, about half directly concern food systems: no poverty (SDG 1), zero hunger (SDG 2), good health and well-being (SDG 3), clean water and sanitation (SDG 6), responsible consumption and production (SDG 12), climate action (SDG 13), life below water (SDG 14), and life on land (SDG 15) (Herrero et al., 2021). Considering both their nutritional significance and their apparent burdens, tackling the problems associated with ASF production systems would seem to align particularly well with these global ambitions. Figure 5 displays the standard icons for those eight SDGs that are directly tied to the food system (Herrero et al., 2021; United Nations, n.d.):

Figure 5: SDGs Concerned with Food Systems

Two widely publicized proposals for mitigating the harms of ASFs in a manner conducive to desirable nutritional outcomes are dietary change and technological innovation. In 2019, the EAT-Lancet Commission released a scientific report which details the parameters of a healthy and sustainable diet for a world bearing 10 billion inhabitants (Willett et al., 2019). Their daily intake recommendations are comprehensive and resemble national FBDGs as well as the HDB, but with the additional constraint of meeting global nutrition needs within the confines of the planetary boundaries (Willett et al., 2019). Though it speaks to a variety of mitigation strategies, first and foremost, the EAT-Lancet Commission urges sweeping dietary change (Willett et al., 2019). Chief among their suggestions, in general, is a drastic reduction in red meat consumption offset by a dramatic increase in plant protein consumption (Willett et al., 2019).

During the 28th Conference of the Parties, in 2023, the UN Environment Programme (UNEP) highlighted the technological strategies to ASF-related problems in their “What’s Cooking?” report, which covers emerging methods for producing protein foods (UNEP, 2023). The UNEP analysis addresses the potential impact of three separate technologies, including: novel plant-based foods, fermentation-derived products, and cultivated meat (UNEP, 2023). Because the latter of these involves the growth and harvest of actual animal cells, of the three options discussed, it stands out as perhaps the most conservative approach as well as the most distant from the dietary change advocated by the EAT-Lancet Commission (UNEP, 2023).

Contingent upon that assumption and based on the understanding that protein food is uniquely significant to nutrition yet uniquely burdensome to the environment and public health, this report seeks to investigate the future of EAT-Lancet's call for dietary change as well as the widespread adoption of cultivated meat.

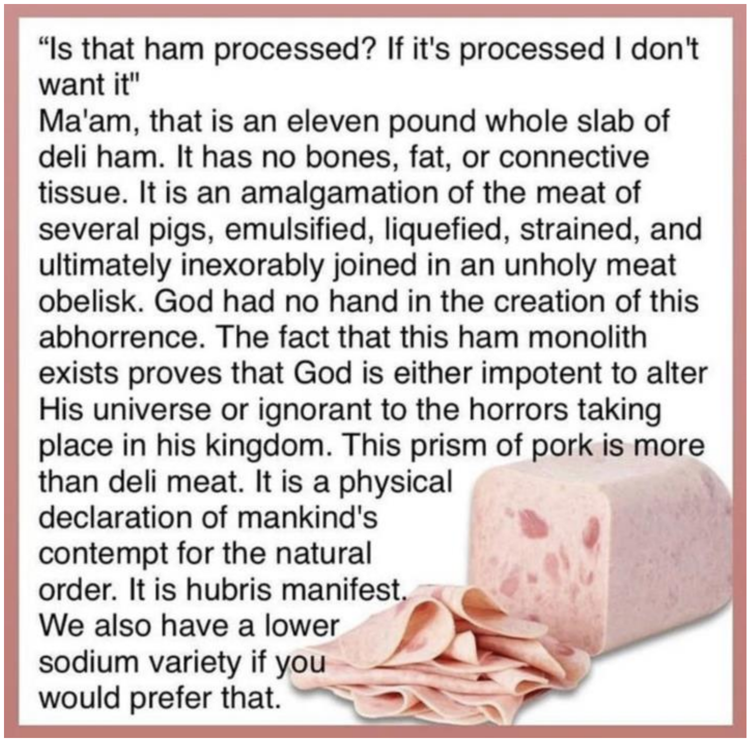


Figure 6: An Internet Meme Commenting on Processed Red Meat (Know Your Meme, n.d.)

"Tsze-kung wished to do away with the offering of a sheep connected with the inauguration of the first day of each month. The Master said, 'Tsze, you love the sheep; I love the ceremony.'"

The Analects (Confucius, 2002)

Dietary Change through the Lens of Protein Security

Projecting Protein Security in 2050

This section examines foods associated with the EAT-Lancet dietary recommendations for the categories of protein and dairy through a lens of food security under varying social, economic, and climatic conditions. More precisely, it models metrics corresponding to the food security dimensions of availability and economic access for 2050. In doing so, this work seeks to better understand the state of protein foods relative to the EAT-Lancet recommendations for current member states of the UN, divided into 22 distinct regions. These modeled metrics can then be used to calculate insightful indicators which may be used by national and international institutions to inform or guide food and agricultural policy decisions.

Typically, analyses of food security consider the whole diet, which would also include food groups such as staple grains, starches, fruits, vegetables, sugars, and oils. However, as this report aims to elicit insights on the future of protein food in general and ASFs in particular, the scope here has narrowed to protein security as a subset of food security.

Concept of Food Security and Chosen Dimensions of Study

According to the High Level Panel of Experts on Food Security and Nutrition (HLPE) (2020), a state of food security "exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life." This comprehensive conceptualization of food security has been traditionally characterized by the four dimensions of availability, access, utilization, and stability (HLPE, 2020; Clapp et al., 2022).

In recent years, experts have advocated for the recognition of two additional dimensions, agency and sustainability (HLPE, 2020; Clapp et al., 2022). For policy purposes, these six dimensions provide food security with a substantial and flexible degree of measurability, allowing researchers to establish benchmarks and track progress over time and place at local, regional, national, and global scales (HLPE, 2020; Clapp et al., 2022).

Table 3, featured in *HLPE Report #15 - Food Security and Nutrition: Building a Global Narrative Towards 2030*, concisely summarizes the current understanding of the six dimensions of food security (HLPE, 2020).

Table 3: Six Dimensions of Food Security

Dimension	Definition
Availability	Having a quantity and quality of food sufficient to satisfy the dietary needs of individuals, free from adverse substances and acceptable within a given culture, supplied through domestic production or imports.
Access (economic, social and physical)	Having personal or household financial means to acquire food for an adequate diet at a level to ensure that satisfaction of other basic needs are not threatened or compromised; and that adequate food is accessible to everyone, including vulnerable individuals and groups.
Utilization	Having an adequate diet, clean water, sanitation and health care to reach a state of nutritional well-being where all physiological needs are met.
Stability	Having the ability to ensure food security in the event of sudden shocks (e.g. an economic, health, conflict or climatic crisis) or cyclical events (e.g. seasonal food insecurity).
Agency	Individuals or groups having the capacity to act independently to make choices about what they eat, the foods they produce, how that food is produced, processed, and distributed, and to engage in policy processes that shape food systems. The protection of agency requires socio-political systems that uphold governance structures that enable the achievement of [food security and nutrition] for all.
Sustainability	Food system practices that contribute to long-term regeneration of natural, social and economic systems, ensuring the food needs of the present generations are met without compromising the food needs of future generations.

Source: HLPE 2020

Experts consistently emphasize interconnectivity and nuance among the six dimensions (HLPE, 2020). A community's or individual's ability to access adequate food, for example, depends on the physical availability of that food, while the reverse need not be true (Clapp et al., 2022). As demonstrated by Sen (1982), famines can still occur even in times of sufficient food availability should a population face some insurmountable economic, physical, or even social barrier to it (Clapp et al., 2022).

Additionally, the relationships and interactions among these dimensions are not strictly linear. Stability and sustainability involve the fulfillment of the other dimensions over the course of time (HLPE, 2020). As conveyed by Table 3, stability concerns communities' and individuals' capacities to withstand short-term shocks that inevitably affect food systems, whether natural or anthropogenic in origin (HLPE, 2020). In theory, a given community could appear food secure on paper today, yet rapidly fall into a state of food insecurity tomorrow under the weight of political unrest or conflict, extreme weather, or a public health event. Case in point, consider the widespread disruptions to the global food system engendered by the COVID-19 pandemic and its accompanying economic recession, which threatened food availability and access worldwide in the form of panic buying, decreased productivity at food processing facilities, elevated prices, and loss of incomes (HLPE, 2020).

Furthermore, if a community is highly reliant on trade for meeting certain food needs, then shocks that primarily affect a significant import partner, or set of partners, could potentially reverberate onshore in the shape of food insecurity. Russia's invasion of Ukraine in early 2022 well illustrates this point (Glauber & Laborde, 2023).

Leading up to the conflict, together Russia and Ukraine represented a major breadbasket for the world, supplying as much as 30 percent of all exported wheat and barley as well as a significant portion of globally traded maize (Glauber & Laborde, 2023). This is to say nothing of Russia's outsized role as a supplier of fertilizers and fossil fuels (Glauber & Laborde, 2023). These exports served, and continue to serve, not only as major sources of food in themselves but also as feed for livestock as well as other indirect inputs for importers' local food production (Glauber & Laborde, 2023). Between Russia's constraining of Ukrainian agricultural export capacity and the West's imposition of sweeping economic sanctions intended to limit trade with Russia, many import-dependent countries, particularly those in the Global South, faced sudden shortages and price increases that threatened food availability and economic access, respectively (Glauber & Laborde, 2023).

Such examples demonstrate that acknowledging interconnectivity is imperative for avoiding potentially negligent assumptions about the state of food security in each location. Considering this, and after careful review of the six dimensions, availability and economic access were chosen as the focal points for this report's examination of protein security as a subset of food security for 2050, especially in relation to the relevant EAT-Lancet dietary recommendations for that same year.

Availability and economic access offer several advantages when serving as starting positions for analysis. First, the two dimensions have a long history of consideration when studying and addressing the issue of food security (Clapp et al., 2022). Both have been officially recognized by FAO as components of food security since at least 2004 through the adoption of the Right to Food Guidelines (Clapp et al., 2022). However, Clapp et al. (2022) note that the precedent is even older. At the 1974 World Food Conference, food security was originally framed in the following terms (Clapp et al., 2022):

> "[the] availability at all times of adequate world food supplies of basic foodstuffs, particularly so as to avoid acute food shortages in the event of widespread crop failure, natural or other disasters, to sustain a steady expansion of food consumption in

> countries with low levels of per capita intake and to offset fluctuations in production and prices."

Second, there is a long-standing tradition of listing availability and access first when recounting the dimensions of food security in policy documents (Clapp et al., 2022; Table 3). This consistent ordering suggests, at least from an advisory perspective, that these two dimensions perhaps represent more foundational components to the understanding or tackling of food security problems. This study operates under this assumption and emulates the precedent by starting analysis with availability before following it with a look at access.

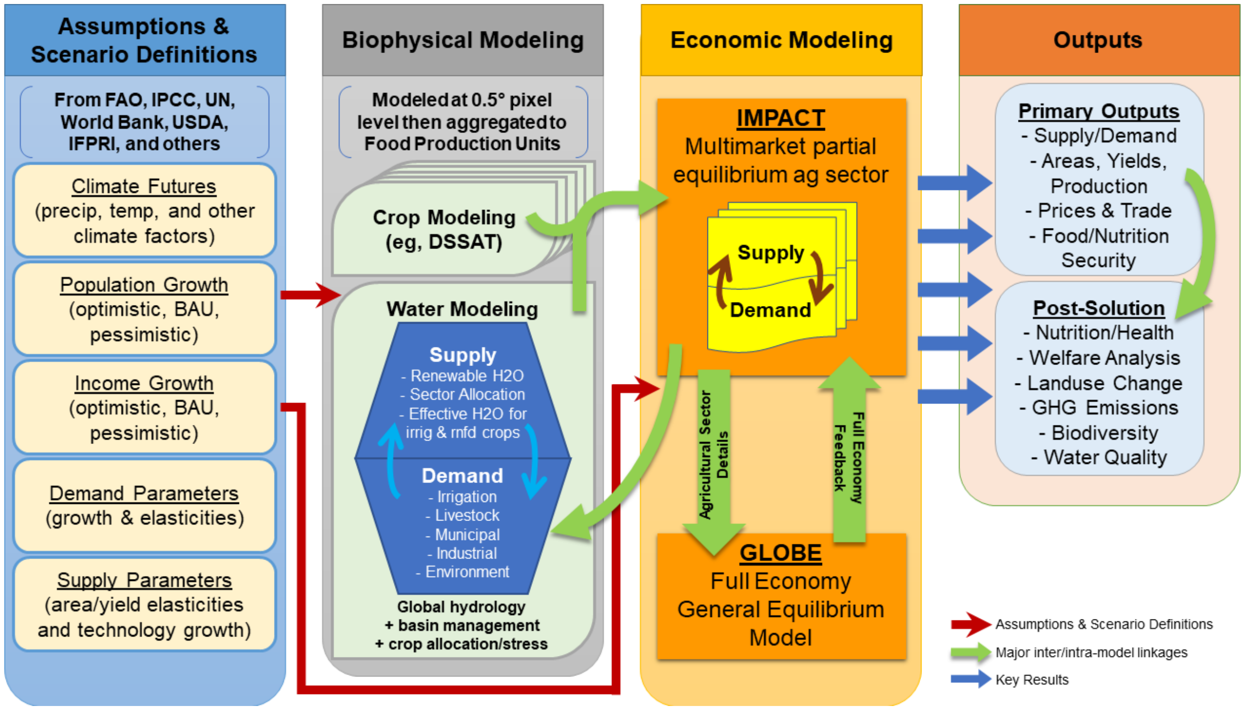
Third, as mentioned in the discussion earlier on the importance of interconnectivity among dimensions, access depends on availability. By looking at both dimensions in tandem, this research can begin to paint a more complex and meaningful picture of future protein security. Finally, both availability and economic access are relatively straightforward to quantify, which may afford the analysis greater objectivity and aid in comparison between foods and food groups as well as between geographic regions and individual UN member states.

Details concerning the process of calculating relevant availability and economic access indicators for protein foods in 2050 are outlined in the sections that follow.

Model and Scenario Selection

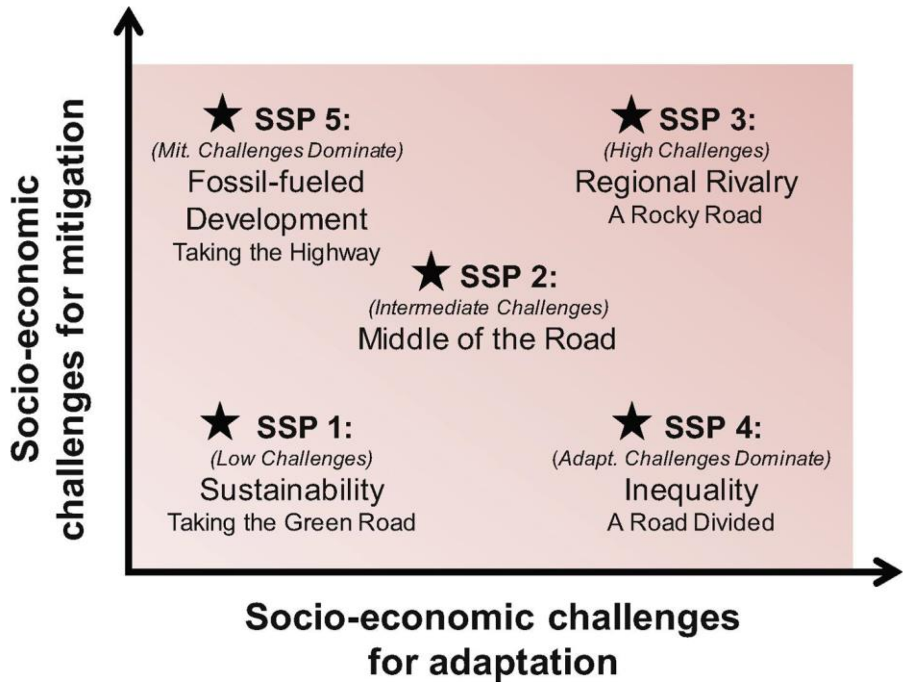
In order to project metrics suitable for gauging availability and economic access for protein foods in 2050, this study employed the International Food Policy Research Institute's (IFPRI) International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). The use of IMPACT is well-represented in research publications, and it has demonstrated comparability with competing models (Valin et al., 2014). IFPRI describes IMPACT as an "integrated modeling system" which effectively incorporates a number of smaller biophysical and economic models (Robinson et al., 2015). Linking climate, crop, and water models with those that account for the complexities of commodity trade in a global market, IMPACT can embed an extensive range of environmental, socioeconomic, political, and technological assumptions in its projected outputs and in a way that is conducive to policy analysis and comparison across selected scenarios (Robinson et al., 2015). Figure 7 presents an overview of IMPACT's assumptions, linkages, and outputs (Robinson et al., 2015).

Figure 7: Overview of IMPACT's Assumptions, Linkages, and Outputs



As for those scenarios of interest, this study relied on the shared socioeconomic pathways (SSPs) framework for its assumptions about future societal responses to climate change. O'Neill et al. (2015) outline five discrete SSP alternatives, which in turn are based on narratives that imagine the future state of the world through five relevant domains: "demographics, human development, economy and lifestyle, policies and institutions, technology, and environment and natural resources." Figure 8 presents the five SSPs graphically, where axes X and Y indicate increasing challenges to adaptation and mitigation, respectively (O'Neill et al., 2015). By using multiple SSPs in modeling, this report seeks to better understand the future of protein security over increasingly difficult barriers to climate mitigation and adaptation in a manner that captures a wide assortment of complicated, societal factors.

Figure 8: Five Socioeconomic Scenarios



To start, this study was limited to the first three SSPs. This scope keeps scenario comparisons linear, where SSP1 represents low challenges to both mitigation and adaptation, SSP2 represents more moderate challenges to both mitigation and adaptation, and SSP3 represents significant challenges to both mitigation and adaptation (O'Neill et al., 2015). For the sake of clarity, Table 4 illustrates the first three SSPs and their associated narratives as summarized by Riahi et al. (2017) and the Government of Canada (2023).

Table 4: Narrative Summaries for the Relevant Socioeconomic Scenarios

Scenario	Narrative Summary
SSP1: Low Challenges, Sustainability	• The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries. • Management of the global commons slowly improves, educational and health investments accelerate the demographic transition, and the emphasis on economic growth shifts toward a broader emphasis on human well-being. • Driven by an increasing commitment to achieving development goals, inequality is reduced both across and within countries. • Consumption is oriented toward low material growth and lower resource and energy intensity.
SSP2: Intermediate Challenges, Middle of the Road	• The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. • Development and income growth proceeds unevenly, with some countries making relatively good progress while others fall short of expectations. • Global and national institutions work toward but make slow progress in achieving sustainable development goals. • Environmental systems experience degradation, although there are some improvements and overall the intensity of resource and energy use declines. • Global population growth is moderate and levels off in the second half of the century. • Income inequality persists or improves only slowly and challenges to reducing vulnerability to societal and environmental changes remain.

SSP3: High Challenges, Regional Rivalry	• A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues. • Policies shift over time to become increasingly oriented toward national and regional security issues. • Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development. • Investments in education and technological development decline. • Economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time. • Population growth is low in industrialized and high in developing countries. • A low international priority for addressing environmental concerns leads to strong environmental degradation in some regions.

Source: Riahi et al. (2017)

Additionally, each SSP can be associated with a representative concentration pathway (RCP), which characterizes a potential climate future through the level of stabilized radiative forcing, measured in watts per square meters, present by the end of the century (Government of Canada, 2023). RCP values range from 1.9 to 8.5 W/m^2, where higher values correspond to more intense warming from greenhouse gases present in the atmosphere (Government of Canada, 2023). Potential SSP-RCP combinations are limited due to irreconcilable future conditions such as SSP1, which assumes low barriers to climate change adaptation and mitigation, and RCP8.5 which supposes the most extreme case of radiative forcing available to the framework (Riahi et al., 2017; Government of Canada, 2023). SSP2, on the other hand, as the intermediate case with regard to climate action, has compatibility with a wider range of possible RCP (Riahi et al., 2017; Government of Canada, 2023). SSP3, with its high barriers to climate change intervention, lends itself to pairings with the harsher RCP options (Riahi et al., 2017; Government of Canada, 2023).

In the spirit of precaution and preference to steer clear of complacency, this study leans pessimistic in its selection of SSP-RCP combinations, opting for the following combinations:

1. SSP1-RCP2.6
2. SSP2-RCP7.0
3. SSP3-RCP8.5

RCP choices inform the climate models used to feed into IMPACT's integrated modeling environment. Table 5 lists the climate models utilized by this study.

Table 5: Climate Models Utilized

Climate Model	
GFDL	Geophysical Fluid Dynamics Laboratory
IPSL	Institut Pierre-Simon Laplace
MPI	Max Planck Institute
MRI	Meteorological Research Institute
UKESM	United Kingdom Earth System Model

Food and Food Groups Considered

For the purposes of this inquiry, the protein food basket comprises those items explicitly classified as “protein sources” by the EAT-Lancet Commission which includes beef, lamb, pork, poultry, eggs, legumes, and tree nuts (Willett et al., 2019). While listed separately from the protein sources in the EAT-Lancet recommendation scheme, the protein food basket for this analysis also includes dairy because it unequivocally represents an ASF category, is grouped together with meat and eggs in the HDB scheme and is otherwise widely recognized as an important supplier of dietary protein (Herforth et al., 2022).

As a key ASF in world diets and a canonical protein source food of the EAT-Lancet dietary guidelines, fish stands out here as a glaring omission (Herforth et al., 2022; Willett et al., 2019). Supplying over three billion people nearly a fifth of their animal protein, fish and seafood represent a core component of global protein security (FAO, 2022). However, the current iteration of IMPACT, Version 3, remains limited regarding projections for this broad category of food (Robinson et al., 2015). The official model description for Version 3 notes that work is underway to integrate fish modules into IMPACT in the future (Robinson et al., 2015). Given this limitation, and for the sake of consistency, only terrestrial protein sources are considered for now.

Though not belonging to the category of ASF, legumes and tree nuts remain indispensable for study within this context because, as suppliers of essential amino acids, they represent EAT-Lancet’s proposed alternative to fill dietary protein gaps left by reducing ASF intakes (Willett et al., 2019). Therefore, this report assesses legumes and tree nuts as both complements of and competitors to ASF.

Table 6 outlines the EAT-Lancet guidelines for daily caloric and macronutrient intakes as they pertain to protein sources and dairy foods (Willett et al., 2019). As recommendations are based on a total caloric intake of 2,500 kilocalories per day, this means that the protein food group, as conceived by this report, contributes around 35.2 percent of a healthy and sustainable diet’s kilocalories, or about 33.6 percent when excluding fish (Willett et al., 2019). Note the variation of suggested kilocalorie or macronutrient intakes among constituent foods.

Table 6: EAT-Lancet Daily Protein Guidelines

Protein Sources and Dairy Foods	Recommended Caloric Intake, kCal/day	Macronutrient Intake (possible range), g/day
Whole milk or derivative equivalents	153	250 (0-500)
Beef and lamb	15	7 (0–14)
Pork	15	7 (0–14)
Chicken and other poultry	62	29 (0-58)
Eggs	19	13 (0-25)
Fish	40	28 (0-100)
Legumes		
Beans/lentils/peas	172	50 (0–100)
Soy foods	112	25 (0–50)
Peanuts	142	25 (0–75)
Tree nuts	149	25
Total	879	459 (25-961)

Source: Willett et al. (2019)

Of note, the EAT-Lancet reference diet accounts for the diversity of food preferences that persist across different cultures, communities, and individuals, which is achieved through two features. First, as seen in the macronutrient column, the recommendations allow for a range of possible intakes in all considered protein foods except for tree nuts (Willett et al., 2019). These ranges begin at zero consumption and extend to about double that of the main target values (Willett et al., 2019). Such a feature accommodates restricted diets like vegetarianism as well as situations where a given food is unavailable. The second feature is exchangeability between comparable foods. The EAT-Lancet report identifies beef and lamb products as exchangeable with pork (Willett et al., 2019). Likewise, chicken and other poultry products are, in theory, exchangeable with eggs, fish, and plant-derived protein sources (Willett et al., 2019). Moreover, all forms of plant protein, whether from legumes or tree nuts, are exchangeable with one another (Willett et al., 2019). Thus, this framework permits a relatively high degree of aggregation in the consideration of protein foods, which raises the question: What is the most appropriate level of granularity to use for this study with regard to protein foods?

This analysis adopts the ASF typology used in IFPRI's *2022 Global Food Policy Report: Climate Change and Food Systems*, which presents red meat, poultry, eggs, and milk (dairy) as discrete subunits of ASF (IFPRI, 2022). Because all plant protein sources are exchangeable according to EAT-Lancet and can serve as an outgroup to ASF, they are considered a discrete group here, simultaneously equivalent to any subunit of ASF as well as ASF in its entirety for the purposes of comparison (Willett et al., 2019). This brings the number of relevant subunits to five: red meat, poultry, eggs, dairy, and plant protein. IMPACT provides outputs for over 60 different agricultural commodities (Robinson et al., 2015). Of these, 16 were mapped by this study to the five subunits of protein food, as illustrated in Table 7.

Table 7: Equivalency between EAT-Lancet and IMPACT Protein Foods

Protein Food Subunit		IMPACT Equivalent Commodities		Recommended Caloric Intake, kCal/day
Animal Source Food	Red Meat	cbeef clamb cpork	Beef Lamb and mutton Pork	30
Animal Source Food	Poultry	cpoul	Poultry	62
Animal Source Food	Eggs	ceggs	Eggs	19
Animal Source Food	Dairy	cmilk	Dairy	153
	Fish	n/a	n/a	40
Plant Protein		cbean cchkp ccowp clent copul cpigp cgrnd cgdml csoyb cothr	Beans Chickpeas Cowpeas Lentils Other pulses Pigeon peas Groundnuts Groundnut meal Soybeans Other crops	575
Total		n/a	n/a	879

Source: Robinson et al. (2015)

Tree nuts contribute significantly to EAT-Lancet's endorsed diet at nearly 17 percent of the total target kilocalories, even when including both fish and dairy in the overall count (Willett et al., 2019). However, IMPACT Version 3 does not provide output figures or projections exclusive to tree nuts (Robinson et al., 2015). Instead, nuts are included under "other crops" in outputs along with cloves, spices, tobacco, rubber, and various non-food fibrous plants (Robinson et al., 2015). The method for handling this issue is addressed in the forthcoming section on the calculation of indicators for availability and economic access.

Figure 9: EAT-Lancet Protein Sources Intake Breakdown, kCal/day

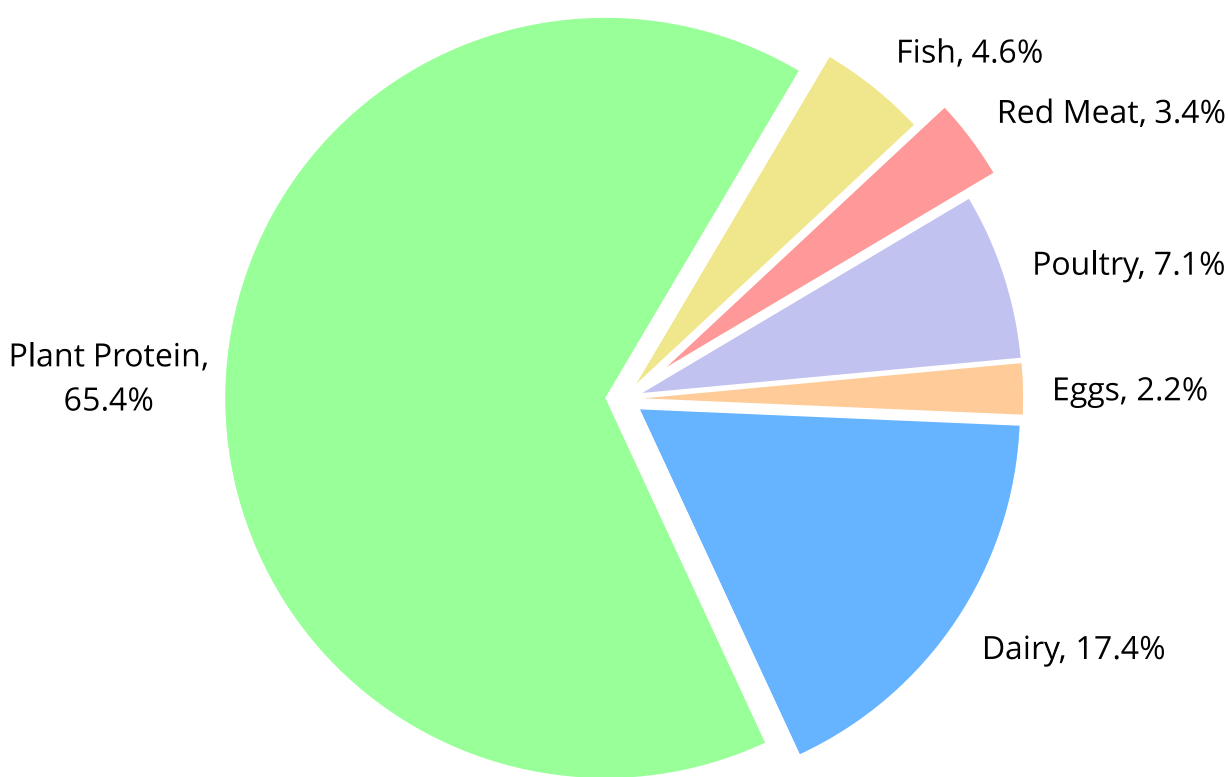


Figure 9 (above) illustrates the caloric contribution of the five protein food subunits (plus fish) to EAT-Lancet's total protein and dairy recommendations. Note the prominence of plant protein relative to red meat.

Role of Religion

Religious affiliation can play an important role in patterns of food consumption, particularly as it relates to ASF. For instance, holding cattle sacred, many adherents to Hinduism abstain from beef consumption (Chouraqui et al., 2021). In fact, surveying in India suggests that most Hindus, 72 percent, view refraining from beef as an obligation of the religion, and although lacto-vegetarianism may be common among adherents, 44 percent, the majority continue to eat meat in some form or another on a regular basis (Pew Research Center, 2021).

Meanwhile, observant Muslims and Jews typically refuse to eat pork in accordance with halal and kosher dietary codes, respectively, but continue to enjoy other categories of meat, assuming it conforms to their prescribed standards of slaughter and culinary preparation (Chouraqui et al., 2021). For Judaism, the outlawing of pigmeat appears in the Tanakh (Jewish Publication Society, 2006):

> "[A]lso the swine—for although it has true hoofs, it does not bring up the cud—is impure for you. You shall not eat of their flesh or touch their carcasses." (Deuteronomy 14:8).

Likewise for Islam, this ban on pork finds a scriptural basis in its central text, the Quran (Quran.com, n.d.):

> "He has only forbidden you ⌜to eat⌝ carrion, blood, swine, and what is slaughtered in the name of any other than Allah. But if someone is compelled by necessity—neither driven by desire nor exceeding immediate need—they will not be sinful. Surely Allah is All-Forgiving, Most Merciful." (Quran 2:173).

Practitioners of other major religions may also engage in selective meat consumption or outright vegetarianism, but with lower consistency than seen in the three aforementioned traditions.

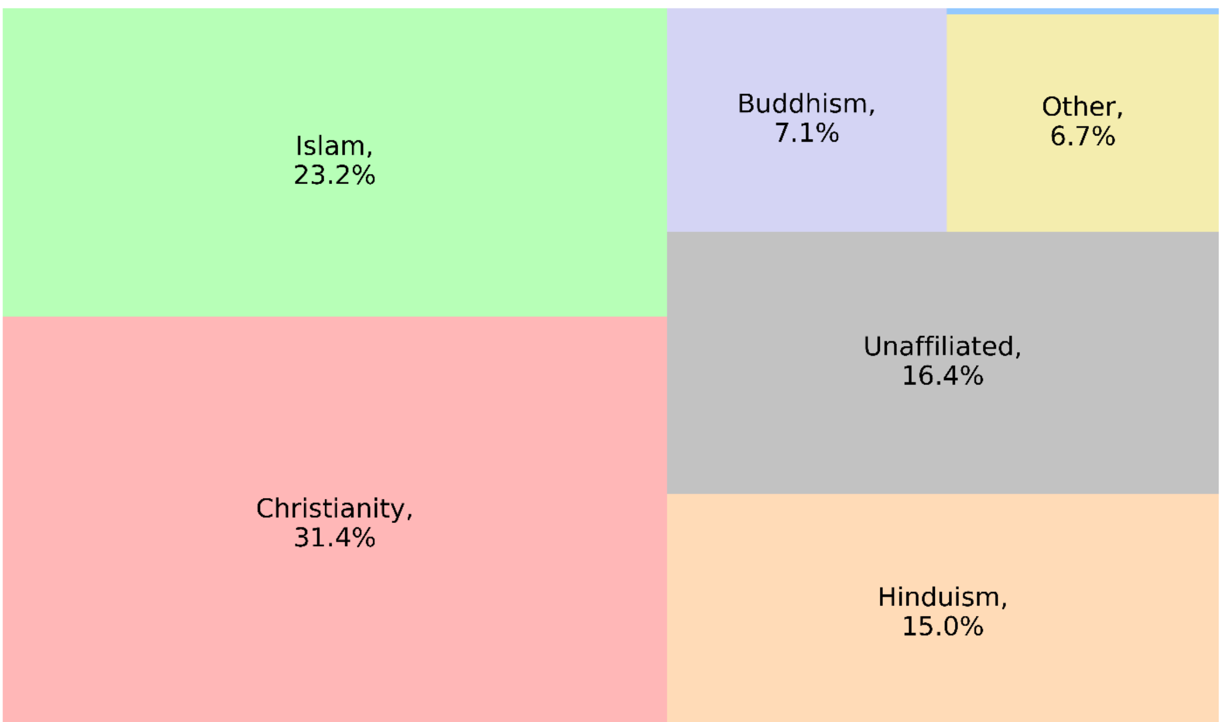
Buddhism, for example, while often viewed as strictly vegetarian in the Western world, does not necessarily proscribe meat consumption for followers, or even the clergy (Wiist et al., 2012; Kaza, 2005). Rather, it appears that most lay Buddhists in the Mahayana traditions of China and Taiwan, for instance, do not consistently keep vegetarian (Tseng, 2020).

Christianity, currently the world's most popular faith tradition, on occasion involves forgoing some combination of animal products (Pew Research Center, 2015). In the Catholic Church, canon law historically banned meat consumption, except for fish, on all Fridays as well as designated ceremonial days (Chouraqui et al., 2021; Vatican, n.d.). In Eastern and Oriental Orthodox Churches, periods of fasting from ASFs comprise significant portions of the liturgical year (Chouraqui et al., 2021). Moreover, some smaller denominations, such as the Seventh-day Adventists, encourage a consistently vegetarian diet (Chouraqui et al., 2021).

Because religion so often restricts individuals' ASF options, especially for adherents of Hinduism, Islam, and Judaism, for the sake of cultural sensitivity, in this study it is considered when assessing the future of protein availability and access within a global context. Appreciating this factor proves paramount upon review of religious demographic projections for 2050.

According to Pew Research Center, in 2010, adherents to Hinduism, Islam, and Judaism together made up approximately 38.4 percent of the global population (Pew Research Center, 2015). Figure 10 displays world religious demographics in 2010 as a treemap (Pew Research Center, 2015).This suggests, assuming the highest levels of dietary code observance, that over a third of people always refrain from at least one type of red meat. This decreased flexibility in food choice, in theory, could affect communities' or individuals' red meat availability and economic access regarding fulfillment of the recommendations proposed by EAT-Lancet.

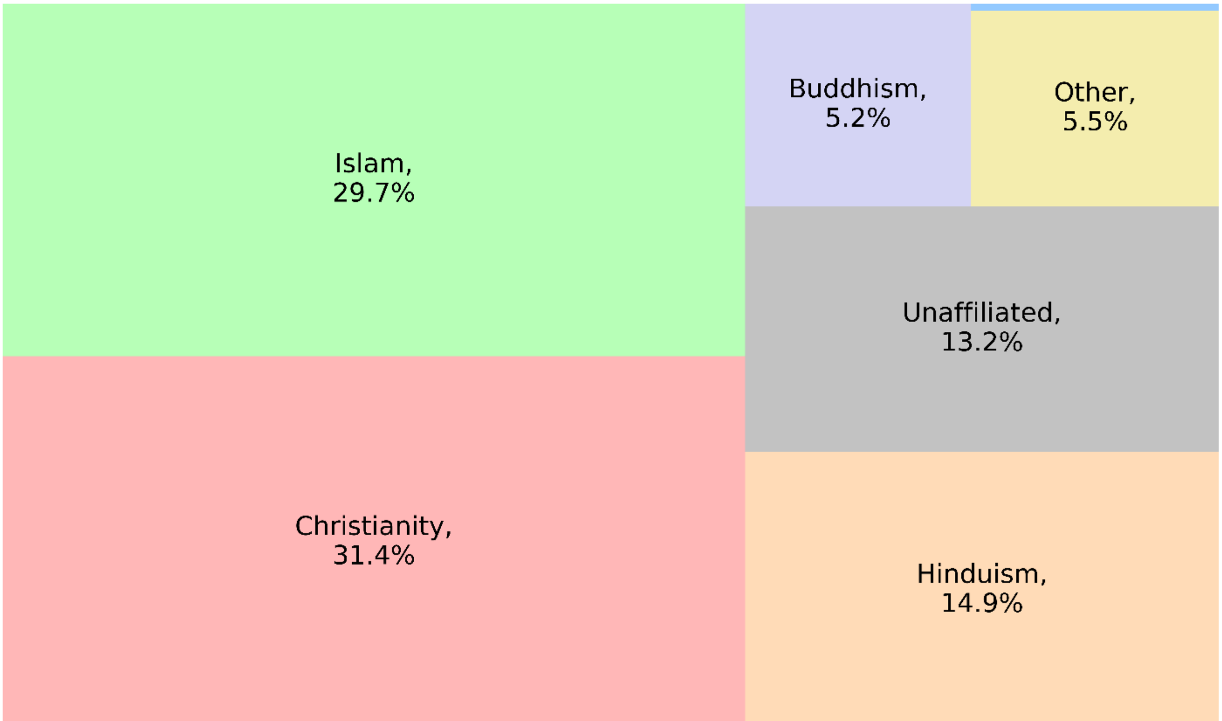
***Figure 10: World Religious Affiliation in 2010*[2]**



Looking toward the target year of 2050, the consideration of faith becomes even more pressing. Based on projections by Pew Research Center (2015), the world will increase in its religiosity (decline in unaffiliated), and Islam will see the greatest growth, approaching 30 percent of the population by 2050. Overall, upwards of 44.8 percent of the world could have a religiously motivated prohibition on consuming at least one type of red meat product. Figure 11 visualizes projected religious affiliations for the world in 2050 (Pew Research Center, 2015).

[2] Judaism appears as the blue line (0.2 percent) and "Other" also includes folk religions.

Figure 11: World Religious Affiliation in 2050[3]



As a way of accounting for the role of religion concerning protein food choices, in the calculation of availability and economic access indicators using IMPACT projections, this analysis omits beef as a consideration or choice in countries where at least half (50 percent) of the population is projected to be Hindu and pork as a consideration or choice when the population is expected to be at least 50 percent Muslim or Jewish. All other countries are unaffected by this red meat constraint.

Countries Considered

The scope for this analysis includes only full member states of the United Nations, which currently includes 193 independent countries, which are grouped into 22 distinct regions for more manageable analysis (United Nations, 2024). IMPACT Version 3 produces relevant outputs for 159 countries; however, several represent aggregations that combine smaller, independent countries with their larger neighbors and sometimes include semi-autonomous areas with otherwise fully independent countries (Robinson et al., 2015).

Geography appears to take priority over legal relationships between parties in an aggregation. Case in point, "Spain Plus" operates as a single country in IMPACT and represents Spain, Andorra, and Gibraltar (Robinson et al., 2015). Spain and Andorra are independent countries

[3] Judaism appears as the blue line (0.2 percent) and "Other" also includes folk religions.

and UN member states while Gibraltar is a dependency of the United Kingdom (United Nations, 2024; United Nations, 2023). “Great Britain Plus” includes the United Kingdom as well as the nearby dependencies of Guernsey, Isle of Man, and Jersey, but not Gibraltar which has greater proximity to Spain (Robinson et al., 2015).

To expand data to include all UN member states as discrete entities, this study, using only output types framed in per capita terms, cloned aggregated data entries across each constituent country (or dependency) and then discarded aggregations and non-member states such as Jersey or Gibraltar from the analysis.

All UN member states assessed in the report were then characterized according to their most granular geographic subregional designation used in the FAO’s *The State of Food Security and Nutrition in the World 2023*, which include (with the count of represented UN member states shown in parentheses): Northern Africa (6), Eastern Africa (18), Middle Africa (9), Southern Africa (5), Western Africa (16), Central Asia (5), Eastern Asia (5), Southeastern Asia (11), Southern Asia (9), Western Asia (17), Caribbean (13), Central America (8), South America (12), Australia and New Zealand (2), Melanesia (4), Micronesia (5), Polynesia (3), Northern America (2), Eastern Europe (10), Northern Europe (10), Southern Europe (14), and Western Europe (9) (FAO et al., 2023).

Note that although it is excluded in the M49 regional classification scheme, San Marino is included with Southern Europe here because FAO groups the small country with that region in several of its health-related assessments (FAO et al., 2023). The same circumstances apply with Monaco in the region of Western Europe (FAO et al., 2023). Additionally, Liechtenstein is included with Western Europe because it is ordinarily grouped with Switzerland in IMPACT and that country is classified as Western European by FAO’s report (Robinson et al., 2015; FAO et al. 2023).

Then, if applicable, UN member states were marked to denote whether they were projected by Pew Research Center to have at least half of their population consisting of either Hindus, Muslims, or Jews in 2050. The calculation of availability and economic access indicators exclude beef as an option for red meat in predominantly Hindu countries and pork as an option for red meat in predominantly Muslim and Jewish countries.

Appendix A lists all considered countries along with their ISO 3166 alpha-3 codes, FAO subregional designations (also referred to as simply regions in this report), and religious affiliation if relevant to protein security by the standards and assumptions of this report. In the religion column “H” signifies at least half Hindu, “I'' signifies at least half Muslim, and “J” signifies at least half Jewish populations in 2050 (CIA, n.d.).

An Indicator for Availability

IMPACT can output data for availability for individual food items in the form of kilocalories per person per day by country (Robinson et al., 2015). Using such information, this study adapts methodology employed by López et al. (2023) to generate an EAT-Lancet healthy reference diet score tailored specifically to the previously defined basket of protein foods. López et al. (2023) considered the whole diet of their subjects, which included 15 food types partitioned into either “encouraged” or “limited” groups.

For encouraged foods, such as whole grains and legumes, subjects were assigned one point for each food that was consumed at the EAT-Lancet recommended target value or more (López et al., 2023). For limited foods, such as red meat or dairy, subjects were assigned a point for each food that was consumed at or below the recommended target (López et al., 2023). After analysis of subjects’ dietary intake data, each subject received a total score that could range from 0 to 15, where a 15 marks full compliance or adherence with the EAT-Lancet recommendations for a healthy diet (López et al., 2023).

Since this study is concerned with protein security on a global rather than community scale, countries take the place of individual human subjects in the design of the indicator. Likewise, national caloric availability, a function of modeled domestic production and international trade as well as other factors for each food, is considered as opposed to dietary intakes derived ultimately from surveys.

The indicator used here, from this point forward referred to as the ‘Protein Score,’ also segregates its food basket (in this case red meat, poultry, eggs, dairy, and plant protein) into two classes for scoring. The encouraged class includes all plant-derived proteins such as legumes and nuts. Countries are assigned one point for plant protein if national caloric availability (expressed as kCal/capita/day) is at least equal to the recommended target intake set by EAT-Lancet. Like the system devised by López et al. (2023), no amount of plant protein availability above the target is penalized.

The limited class, essentially the ASF class, includes the remaining four protein subunits. For these foods, countries are assigned one point when national caloric availability is at least equal to the target, but no greater than double the target. In the EAT-Lancet diet, recommended intakes for ASF, when expressed in macronutrient terms, allow a range from no consumption to approximately twice the target (Willett et al., 2019). This pattern is simply applied to kilocalories for the Protein Score. In capping the permitted ASF availability eligible for receiving one point, this indicator is understood to implicitly embed concern for the dimension of sustainability (see Table 3), supposing that excessive availability unnecessarily contributes to stress on planetary boundaries.

Unlike López et al. (2023), this report does not reward an availability below the EAT-Lancet target for limited foods, as availability here reflects the capacity of individuals in a country or region to meet the target values based only on the physical presence of the food and in a manner that remains sensitive to cultural preferences. Protein Scores for regions are found by taking the average of the national caloric availability of each of their constituent countries. Food classes and scoring criteria are otherwise unaltered.

As mentioned in the previous section on foods considered for this analysis, tree nuts constitute a large portion of EAT-Lancet's proposed protein food calories. However, IMPACT aggregates tree nuts with cloves, spices, tobacco, rubber, and other non-food items (Robinson et al., 2015; Smith et al., 2022). This means that the output of national caloric availability for this aggregation includes both items that contribute some amount of caloric value, like cloves, as well as those inedible items which do not, such as rubber. In order to parse out food availability of tree nuts from the IMPACT aggregation in a pollinator study, Smith et al. (2022) referred to food balance sheets from FAO, calculating the portion that nuts historically contribute to a basket of those food items that are contained in IMPACT's "other" grouping (FAOSTAT, n.d.).

This study adopted and adapted that approach. To calculate the national caloric availability given by tree nuts in "other," food balance sheets from FAO for the years 2010 through 2021 were consulted (FAOSTAT, n.d.). FAO's food balance sheets provide national data for "Food supply (kCal/capita/day)" for each of the edible items in "other": nuts, cloves, and spices (FAOSTAT, n.d.). From these entries the average contribution of nuts to the total of the three foods was calculated for each country and then multiplied by the appropriate national caloric availability figure given for "other" by IMPACT. For countries without adequate data in FAOSTAT, the obtainable UN member states' average for nuts' contribution to the caloric availability of "other" was applied.

An Indicator for Access

For measuring economic access to protein food, this study adopted the methodology for calculating the Cost and Affordability of a Healthy Diet (CoAHD) in order to find what this report calls 'Cost of Protein Adequacy' for all UN member states and FAO-designated subregions (Herforth et al., 2023). Ordinarily, the CoAHD methodology is used to find the daily least-cost way to meet minimum dietary standards, which may be those set by national governments in the form of food-based dietary guidelines (FBDG) but may also apply to the EAT-Lancet reference diet (Herforth et al., 2023; Food Prices for Nutrition, 2023).

Tufts University Friedman School of Nutrition Science and Policy's Food Prices for Nutrition project provides a workbook and food item database to facilitate calculations of CoAHD (Food Prices for Nutrition, 2023). Their tool requires inputs such as price observations for individual food items in a given market at a given time as well as information about the caloric composition of the edible portions of those foods (Food Prices for Nutrition, 2023).

Users may select an existing FBDG or input a custom scheme and then select the minimum number of foods needed to meet the needs each food group outlined by the diet, for instance, two foods for meeting fruits or just one food to meet dairy recommendations (Food Prices for

Nutrition, 2023). Specifying a minimum number of foods per food group enforces some level of dietary diversity. Due to the limited options for ASFs in IMPACT, this study only selected one food type for each ASF subunit. For plant protein, the study required that two food items be selected as the IMPACT options are more diverse and, as discussed earlier, plant proteins are more likely to require combination in order to supply humans EAAs at sufficient levels. The system, having all necessary data, will reveal the daily least-cost way to meet the defined diet in terms of both food groups and minimum food choices for each group (Food Prices for Nutrition, 2023).

Because this report focuses exclusively on protein foods in relation to the EAT-Lancet diet, in computing the Cost of Protein Adequacy the selected dietary guidelines matched the protein food subunits and the recommended caloric intakes shown in Table 7. Projected consumer price data for each food for each country were provided by IMPACT. Using the provided Tufts food item database, the caloric values of the edible portion of each food appearing in the dataset were determined, with some modifications to account for the generality of certain food items handled by IMPACT (Food Prices for Nutrition, 2023; Appendix B). Once Cost of Protein Adequacy is obtained, it can be split by source, either animal or plant, and divided by the target caloric values for each source to find cost per kilocalorie.

Results

At both the national and regional levels, in all modeled scenarios, no area meets ideal protein availability (i.e., a calculated protein score of five) for 2050. The vast majority of countries and regions experience over-availability of red meat, and all fail to provide for the EAT-Lancet target for plant protein. Looking regionally, only Southern Asia under SSP2 and SSP3 maintains a healthy and sustainable availability of red meat products.

The highest protein score achieved regionally is three, which occurs in South America under SSP1 and both South and Central America under SSP2 and SSP3. The lowest protein score achieved regionally is zero, which occurs in Eastern, Middle, Western and Africa, Eastern Asia, Northern America, and Southern Asia under SSP1 as well as Eastern, Middle, Southern, and Western Africa, Eastern Asia, Melanesia, and Northern America under both SSP2 and SSP3. Note that availability data for dairy is absent for Equatorial Guinea (Middle Africa) as well as for plant protein for Equatorial Guinea, Brunei Darussalam (Southeastern Asia), and Singapore (Southeastern Asia).

As for economic access, the daily least-cost for animal source protein far exceeds the daily least-cost for plant source protein in all scenarios, in both terms of absolute cost and cost per kilocalorie. At the regional level, fulfilling the combined targets for animal source protein is universally most expensive under SSP1 and universally least expensive under SSP3. For plant source protein at the regional level, cost is generally highest under SSP2.

Table 8 (SSP1), Table 9 (SSP2), and Table 10 (SSP3) display results for the calculated availability ratios relative to EAT-Lancet targets for each protein food subunit and the corresponding Protein Score by region where red represents over-availability, yellow represents under-availability, and green represents acceptable availability by the standards of this report:

Table 8: Protein Score Results for SSP1, by Subregion

	SSP1: Low Challenges, Sustainability					
	Protein Score	**Red Meat**	**Poultry**	**Eggs**	**Dairy**	**Plant Protein**
Australia and N.Z.	2	12.88	2.77	1.55	1.48	0.17
Caribbean	2	6.23	3.65	1.06	1.05	0.20
Central America	2	3.73	2.01	1.88	1.06	0.29
Central Asia	1	7.55	0.38	0.97	1.78	0.03
Eastern Africa	0	5.43	0.65	0.58	0.82	0.34
Eastern Asia	0	11.51	0.69	2.43	0.61	0.23
Eastern Europe	2	7.58	1.60	2.69	1.77	0.08
Melanesia	1	12.62	1.15	0.85	0.21	0.14
Micronesia	1	14.84	3.93	1.94	0.93	0.04
Middle Africa	0	6.26	0.84	0.40	0.48	0.37
Northern Africa	2	4.34	0.87	1.34	1.01	0.23
Northern America	0	9.24	2.82	2.49	2.15	0.27
Northern Europe	1	11.36	1.37	2.21	2.61	0.09
Polynesia	1	14.84	3.93	1.94	0.93	0.04
South America	3	6.87	1.88	1.52	1.05	0.15
Southeastern Asia	2	6.22	1.40	1.90	0.36	0.19
Southern Africa	1	6.57	1.06	0.78	0.76	0.17
Southern Asia	0	2.11	0.60	0.86	0.84	0.21
Southern Europe	1	8.75	0.99	1.74	2.05	0.20
Western Africa	0	4.92	0.67	0.60	0.48	0.31
Western Asia	2	5.16	2.36	1.88	1.37	0.24
Western Europe	1	11.77	1.21	2.45	2.51	0.14

Table 9: Protein Score Results for SSP2, by Subregion

	SSP2: Intermediate Challenges, Middle of the Road					
	Protein Score	**Red Meat**	**Poultry**	**Eggs**	**Dairy**	**Plant Protein**
Australia and N.Z.	2	12.66	2.71	1.58	1.48	0.16
Caribbean	1	5.55	3.23	0.98	1.05	0.19
Central America	3	3.49	1.84	1.82	1.06	0.27
Central Asia	1	7.26	0.34	0.96	1.78	0.03
Eastern Africa	0	3.80	0.49	0.48	0.71	0.30
Eastern Asia	0	10.71	0.67	2.42	0.59	0.22
Eastern Europe	2	7.50	1.56	2.67	1.77	0.08
Melanesia	0	9.70	0.85	0.68	0.21	0.13
Micronesia	1	12.60	3.31	1.70	0.92	0.03
Middle Africa	0	4.60	0.65	0.33	0.42	0.33
Northern Africa	2	3.74	0.81	1.28	1.03	0.22
Northern America	0	9.34	2.87	2.52	2.16	0.26
Northern Europe	1	11.46	1.37	2.23	2.62	0.09
Polynesia	1	12.60	3.31	1.70	0.92	0.03
South America	3	6.59	1.78	1.48	1.02	0.14
Southeastern Asia	2	5.45	1.26	1.71	0.35	0.17
Southern Africa	0	5.70	0.93	0.74	0.74	0.16
Southern Asia	1	1.79	0.50	0.75	0.79	0.19
Southern Europe	1	8.75	0.98	1.77	2.05	0.19
Western Africa	0	3.59	0.48	0.49	0.43	0.27
Western Asia	2	4.95	2.31	1.84	1.35	0.23
Western Europe	1	11.90	1.23	2.50	2.51	0.13

Table 10: Protein Score Results for SSP3, by Subregion

	SSP3: High Challenges, Regional Rivalry					
	Protein Score	Red Meat	Poultry	Eggs	Dairy	Plant Protein
Australia and N.Z.	2	12.67	2.72	1.60	1.48	0.16
Caribbean	1	4.83	2.80	0.90	1.06	0.19
Central America	3	3.25	1.68	1.75	1.06	0.25
Central Asia	1	6.95	0.33	0.95	1.77	0.03
Eastern Africa	0	2.82	0.38	0.40	0.65	0.27
Eastern Asia	0	9.86	0.65	2.43	0.58	0.21
Eastern Europe	2	7.47	1.50	2.67	1.77	0.08
Melanesia	0	7.69	0.66	0.57	0.21	0.13
Micronesia	1	10.23	2.65	1.45	0.93	0.03
Middle Africa	0	3.51	0.52	0.28	0.38	0.30
Northern Africa	2	3.19	0.74	1.21	1.06	0.21
Northern America	0	9.54	3.04	2.55	2.17	0.26
Northern Europe	1	11.70	1.36	2.28	2.64	0.08
Polynesia	1	10.23	2.65	1.45	0.93	0.03
South America	3	6.33	1.69	1.44	1.00	0.14
Southeastern Asia	2	4.79	1.15	1.56	0.34	0.16
Southern Africa	0	4.82	0.80	0.68	0.71	0.15
Southern Asia	1	1.53	0.42	0.65	0.75	0.17
Southern Europe	1	8.83	0.96	1.81	2.04	0.19
Western Africa	0	2.70	0.35	0.41	0.40	0.25
Western Asia	2	4.78	2.30	1.80	1.36	0.23
Western Europe	1	12.22	1.24	2.61	2.53	0.13

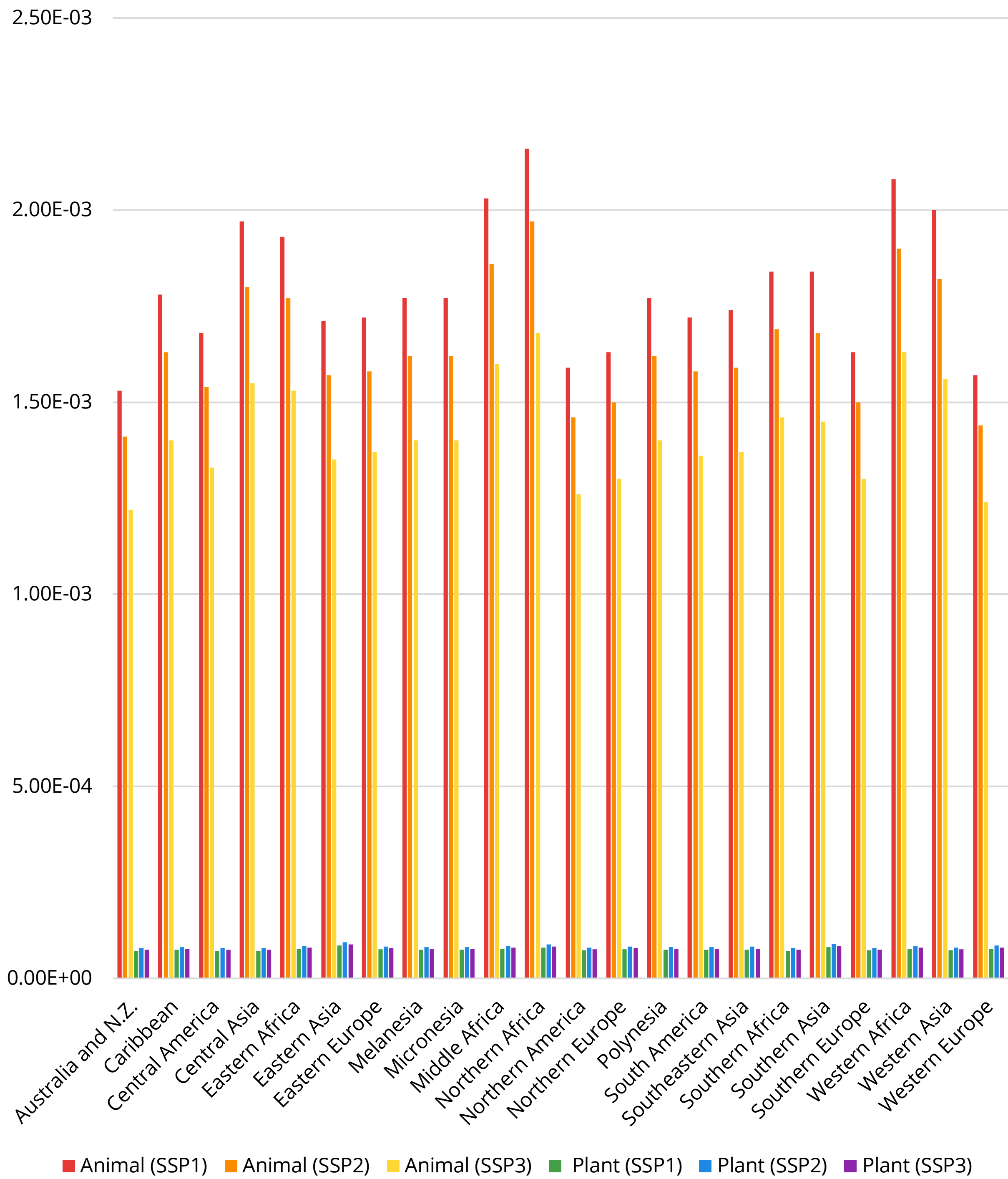
Table 11 displays results for the Cost of Protein Adequacy ($2005) for each scenario by FAO subregion, split into animal and plant protein portions and rounded to the nearest whole cent:

Table 11: Cost of Protein Adequacy Results for SSP1-3, by Protein Type and Subregion

	Cost of Protein Adequacy (Animal Portion), $2005			**Cost of Protein Adequacy (Plant Portion), $2005**		
	SSP1	**SSP2**	**SSP3**	**SSP1**	**SSP2**	**SSP3**
Australia and N.Z.	0.40	0.37	0.32	0.04	0.05	0.04
Caribbean	0.47	0.43	0.37	0.04	0.05	0.04
Central America	0.44	0.41	0.35	0.04	0.05	0.04
Central Asia	0.52	0.48	0.41	0.04	0.05	0.04
Eastern Africa	0.51	0.47	0.40	0.04	0.05	0.05
Eastern Asia	0.45	0.41	0.36	0.05	0.05	0.05
Eastern Europe	0.46	0.42	0.36	0.04	0.05	0.04
Melanesia	0.47	0.43	0.37	0.04	0.05	0.04
Micronesia	0.47	0.43	0.37	0.04	0.05	0.04
Middle Africa	0.54	0.49	0.42	0.04	0.05	0.05
Northern Africa	0.57	0.52	0.44	0.05	0.05	0.05
Northern America	0.42	0.38	0.33	0.04	0.05	0.04
Northern Europe	0.43	0.40	0.34	0.04	0.05	0.05
Polynesia	0.47	0.43	0.37	0.04	0.05	0.04
South America	0.45	0.42	0.36	0.04	0.05	0.04
Southeastern Asia	0.46	0.42	0.36	0.04	0.05	0.04
Southern Africa	0.49	0.45	0.39	0.04	0.05	0.04
Southern Asia	0.49	0.44	0.38	0.05	0.05	0.05
Southern Europe	0.43	0.40	0.34	0.04	0.05	0.04
Western Africa	0.55	0.50	0.43	0.04	0.05	0.05
Western Asia	0.53	0.48	0.41	0.04	0.05	0.04
Western Europe	0.41	0.38	0.33	0.04	0.05	0.05

Figure 12 illustrates Cost of Protein Adequacy ($2005) for each scenario by FAO subregion, split into animal and protein portions and divided by the target kilocalories for those sources:

Figure 12: Animal versus Plant Protein Sources, Cost per kCal ($2005), by Subregion



Discussion

Perhaps most salient, the results of this study suggest that no UN member state, nor region thereof, will have adequate availability of plant protein in 2050 under any of the modeled scenarios. Given that plant protein should supply approximately 65.4 percent of an individual's target protein kilocalories according to the EAT-Lancet diet, the modeling projects a striking global shortfall (Figure 9, Willett et al., 2019). Meanwhile, red meat, which should only supply about 3.4 percent of target protein kilocalories, is almost universally over-supplied worldwide under all scenarios (Figure 9, Willett et al., 2019). As for the remaining ASF food items, in all regions, under all modeled scenarios, these products are more likely to be under-supplied than over-supplied.

In terms of cost, plant source protein is substantially cheaper than animal source protein in 2050 under all scenarios. While lower costs should be expected to contribute positively to economic access, in light of the availability results, this factor may not offer meaningful benefit to population-level protein security from a national or regional policy perspective. Taken together, these calculated indicators may raise doubts regarding the feasibility of EAT-Lancet's protein proposals in the absence of proactive measures to curb red meat and at the same time bolster plant protein availability.

In future work, this research can be augmented in several meaningful ways. First, given fish and seafood's significance to global diets, it will be beneficial to include this category when IMPACT is capable of modeling it. Second, considering the somewhat ambiguous treatment of tree nuts in IMPACT, either increased specificity in the future iterations of the model or a more sophisticated method of parsing them could improve quality of the projections. It is possible that the severity of the observed under-supply of plant protein worldwide could be the result of poor specificity.

Likewise, should IMPACT expand in terms of granularity for either its covered foods or countries, data quality could improve. This study did not account for alternative diets like vegetarianism or those of minority religious populations, which could be remedied in the future with more detailed demographic data or projections. Finally, because the scope of the scenarios was limited to SSP1 through SSP3 where each SSP is only paired with one RCP, in the interest of greater breadth, this work could be enhanced through consideration of SSP4 and SSP5 as well as additional SSP-RCP configurations.

In the next section, this report will analyze the strengths, weaknesses, opportunities, and threats (SWOT) associated with cultivated meat- a potential alternative mitigation strategy to the dietary change advocated by EAT-Lancet. This shift in attention will then open discussion to burgeoning policy approaches to the technology at both the federal and state levels in the United States.

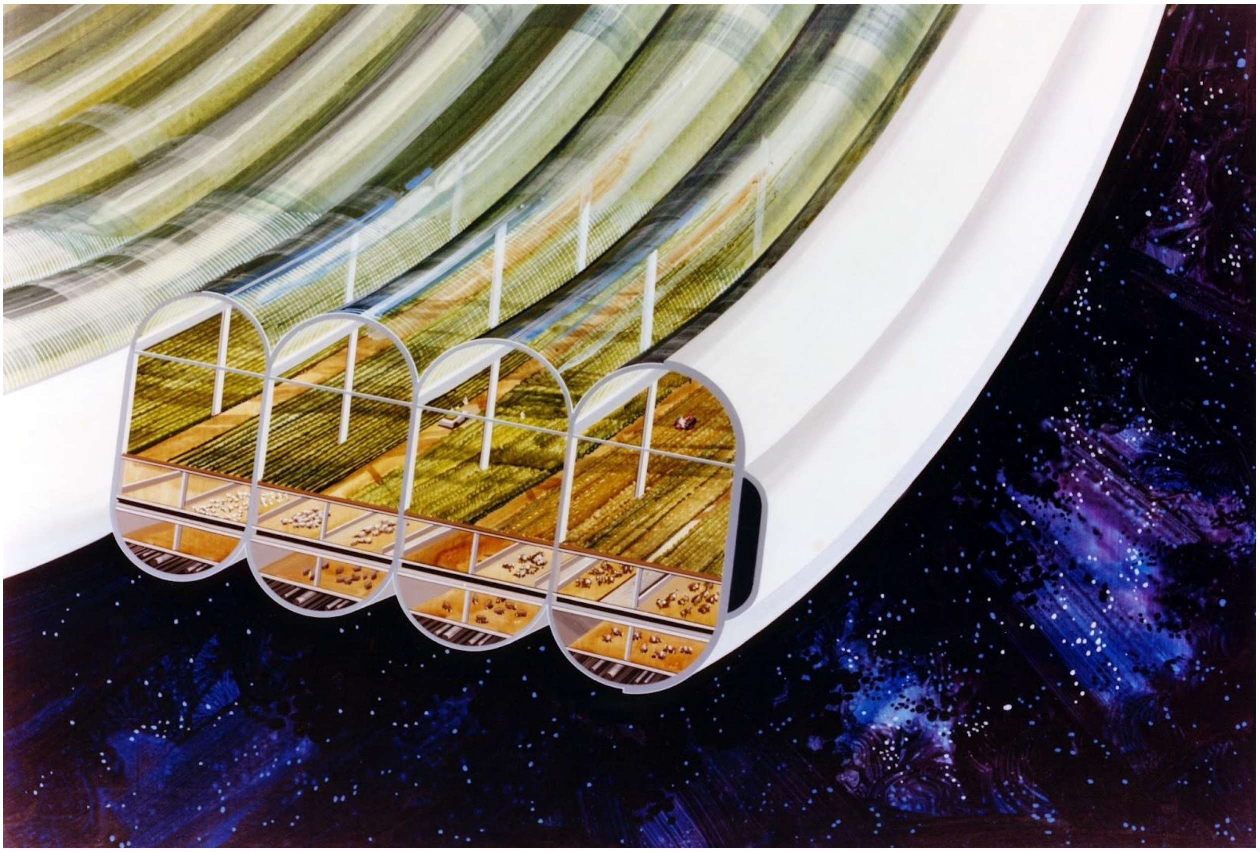


Figure 13: Concept Art for Agricultural Modules on a Space Habitat (Guidice, n.d.)

"With a greater knowledge of what are called hormones, i.e. the chemical messengers in our blood, it will be possible to control growth. We shall escape the absurdity of growing a whole chicken in order to eat the breast or wing, by growing these parts separately under a suitable medium."

Winston Churchill, 1931

Issues and Burgeoning Policy in Cultivated Meat

Technology Overview

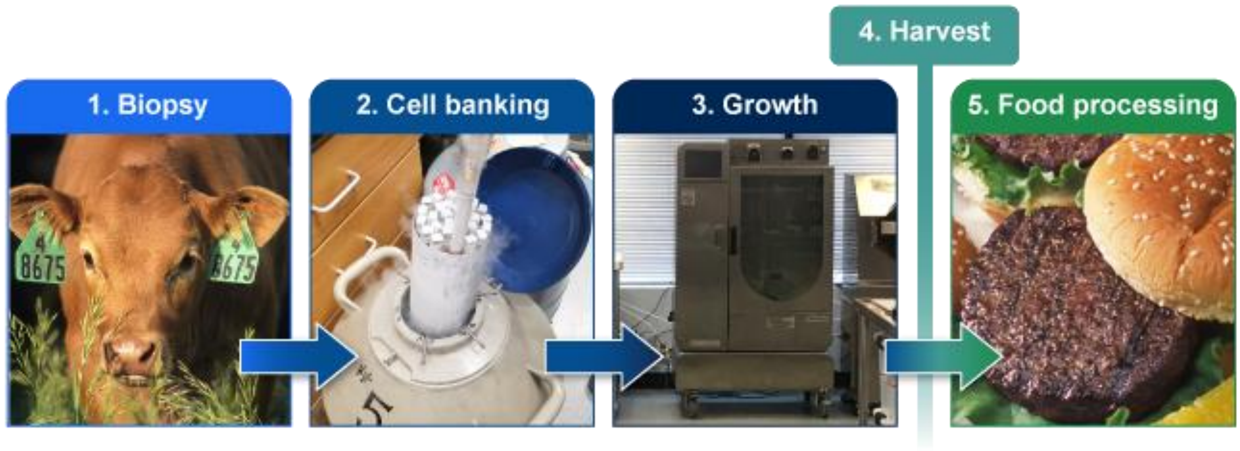
In August of 2013, before a live London audience, Maastricht University researcher Dr. Mark Post unveiled a slaughter-free hamburger generated by culturing bovine skeletal muscle stem cells (Mattick et al., 2015; Fountain, 2013). Notwithstanding lackluster taste reviews, the patty demonstrated the technical feasibility of producing meat through cellular agricultural means (Fountain, 2013). Described variously as cultivated, cell-cultivated, cultured, cell-cultured, in-vitro, and lab-grown, this emerging technology platform for meat presents a potentially transformative solution to many of the previously discussed problems which arise from conventional meat production systems (Fountain, 2013; UNEP, 2023; Benson & Greene, 2023; GAO, 2020).

In essence, producing cultivated meat takes place over five phases (UNEP, 2023; Benson & Greene 2023; GAO, 2020). First, the appropriate cells are extracted from a living animal through a biopsy (UNEP, 2023; Benson & Greene 2023; GAO, 2020). Next, those sampled cells undergo a review process where cells are selected according to attributes like proliferation behavior, nutritional value, and resiliency to stress (UNEP, 2023). Cells may innately exhibit the desired set of traits, or they may be genetically modified at this stage by producers to express them (UNEP, 2023; Benson & Greene, 2023).

Once viable cells are obtained, they may be banked for a later date, otherwise they move to the growth phase (UNEP, 2023; Benson & Greene, 2023; GAO, 2020). There, the cells enter a bioreactor containing a culture medium with the hormonal and nutritional resources necessary to spur proliferation and differentiation into the target cell types under accommodating temperature, pH, oxygen, and carbon dioxide conditions (UNEP, 2023; Benson & Greene, 2023). To replicate the structural and textural characteristics of conventional meat products, the bioreactor may also contain a scaffold to which growing cells adhere (UNEP, 2023; Benson & Greene, 2023; GAO, 2020).

After a suitable maturation period, producers harvest the cultivated cells from the bioreactor, culture medium, and if inedible, the scaffold material (UNEP, 2023; Benson & Greene, 2023; GAO, 2020). Finally, mature cells continue to the food processing phase. For now, this final phase of production largely follows that of more processed conventional meat products, like chicken nuggets (UNEP, 2023). It remains to be seen whether future advancements in technology will facilitate the production of more intact meat products like chicken breast (UNEP, 2023). Figure 14 summarizes the basic cultivated meat production process (GAO, 2020).

Figure 14: Five Basic Phases of Cultivated Meat Production (GAO, 2020)



Sources: GAO and U.S. Department of Agriculture Agricultural Research Service. | GAO-20-325

Though proven as a technical concept, cultivated meat has yet to reach widespread commercialization (UNEP, 2023; Benson & Greene, 2023). In 2023, the Congressional Research Service reported that over 150 individual firms were operating in this nascent industry, with a majority located in the United States, the United Kingdom, Singapore, and Israel (Benson & Greene, 2023). As of early 2024, three national governments have approved of the public sale of cultivated meat products: the US, Singapore, and Israel (Benson & Greene, 2023; Aleccia, 2024).

The US presents an interesting regulatory environment because subnational governments (i.e., the states) can set policies concurrent to those of the federal government, making oversight of cultivated meat a potentially contentious and complex area of administration (Spring & Bence, 2022). For this reason, after conducting a qualitative strengths, weaknesses, opportunities, and threats (or SWOT) analysis for the future of cultivated meat as a technology platform, this report will examine the burgeoning policies governing it at both federal and state levels in the United States.

SWOT Analysis

SWOT is a strategic planning approach commonly utilized by organizations to elucidate a comprehensive understanding of the competing factors which affect decision-making on a given subject (United States Economic Development Administration, n.d.). This report adopts the approach in order to better appreciate select advantages and disadvantages of supporting the further development of cultivated meat as an alternative to dietary change for mitigating the negative impacts of ASFs. In doing so, this report touches on both the technical and social aspects of cultivated meat relevant to long-term policy and planning perspective. Table 12 provides a high level summary of the SWOT factors considered.

Table 12: Summary of SWOT Analysis for Cultivated Meat

Strengths	**Weaknesses**
• Nutritional equivalency • Potential reductions in GHG emissions • Decreased land and water inputs • Lower zoonotic disease risk • Animal welfare gains	• Potential increase in GHG emissions • High cost of production
Opportunities	**Threats**
• Novel products • Long-term space mission applications	• Inability to scale production • Societal resistance

Strengths

Although UNEP makes clear that additional research is still required, because cultivated meat is comprised of actual animal cells identical to those in conventional meat products, they could be nutritionally equivalent, in theory serving as a complete source of AAs as well as other important nutrients (UNEP, 2023). Additionally, industry players continually seek to emulate the physical forms and sensory features of conventional meat (UNEP, 2023). As techniques mature, cultivated meats could eventually replace their conventional counterparts without disrupting culinary patterns, dietary preferences, or protein quality of preferred foods. In the most optimistic outcome, cultivated meat products perfectly or near-perfectly replicate conventional products, allowing communities to reap important environmental, health, and welfare benefits without sacrificing their desired diets or lifestyles.

According to the UNEP report on alternative proteins, a single cow could feed about five people in a year (UNEP, 2023). Utilizing cultivated meat technology in its early stage of development, a single cow could supply food for a group of 2,000 people in a year (UNEP, 2023). In projections of the technology at an advanced stage of development and optimization, this figure jumps to 100 million people each year, but could be even greater as techniques improve (UNEP, 2023). This substantial drop in the number of cows needed relative to the population of humans fed results from the ability to perform repeated biopsies on a single cow (UNEP, 2023). Under the assumption that the minimum viable herd of cattle to prevent problems with inbreeding is 500, Melzener et al. (2021) projected that with highly efficient and effective stem cell sampling, just one herd of this size could potentially supply all of Europe’s beef.

If such dramatic reductions can apply across all livestock populations and world regions, this could hold profound implications for environmental strain and natural resource usage. UNEP reviewed six forward-looking life cycle assessments (LCAs) for cultivated meat, finding that with optimally efficient production techniques powered by renewable energy, cultivated meat could emit around 40 times less GHGs than conventional beef and about a quarter of the emissions associated with conventional chicken and pork (UNEP, 2023). In terms of land use, the benefit of cultivated meat is recognizable across all of the LCAs with reductions of up to 99 percent per kilogram for both beef and pork and as much as 98 percent per kilogram for chicken (UNEP, 2023). Additionally, UNEP reports that the feed conversion ratio for cultivated meat could exceed the efficiency of the current most efficient livestock, chickens, by a factor of three (UNEP, 2023).

According to Poore and Nemecek (2018b), producing a kilogram of conventional pork, beef, and poultry is associated with freshwater withdrawals of 1,796 liters, 1,451 liters, and 660 liters, respectively. The UNEP review of LCAs shows that in the most water-intensive projection, producing one kilogram of cultivated meat (of unspecified type) may only require up to 540 liters (UNEP, 2023).

As discussed in the first section of this report, a perpetual concern with conventional meat production is zoonotic disease risk. Due to their reliance on significantly smaller livestock populations, cultivated meat production systems would likely entail much fewer human-animal interactions, which would reduce opportunities for the interspecies transfer of pathogens (UNEP, 2023). As the often cramped and unsanitary conditions of today's conventional systems fade to irrelevancy, rates of antibiotic use, and therefore the selective pressure on bacteria for developing resistance, could also decrease (UNEP, 2023).

Moreover, cultivated meat offers several quality control advantages in its production timeline. Before and at the biopsy phase, sampled animals could undergo rigorous health monitoring and examinations to minimize contaminant or pathogen risk (UNEP, 2023). In the second phase, biopsied cells can be thoroughly screened by technicians to ensure that disease-causing elements are absent before mass proliferation (UNEP, 2023). Because cells are cultured in highly controlled bioreactors, cultivated meat may also reduce livestock-wildlife interactions as well as human exposure to environmental contaminants that enter through ASF such as methylmercury in fish and seafood products (UNEP, 2023).

Finally, another strong point of cultivated meat stemming from its decreased reliance on large livestock populations is animal welfare. For now, producing cultivated meat still necessitates the rearing and maintenance of animals to serve as cell donors (UNEP, 2023). However, as discussed earlier, the population size of those livestock is expected to be substantially lower than those in conventional meat production systems (UNEP, 2023; Melzener et al., 2021).

Compared with slaughter, the biopsy process is a minimally invasive procedure, involving only the extraction of a small muscle sample using a needle or minor incision (UNEP, 2023). The UNEP report suggests that such a procedure would likely be comparable in comfort level to a routine blood sample when a needle is used and not considerably worse when using an incision (UNEP, 2023). In the future, however, biopsies may be rendered obsolete, as researchers pursue cell lines modified to enable an unlimited capacity for proliferation (UNEP, 2023).

Should they realize such a development, reliance on maintained livestock populations may shrink even further, potentially minimizing hardship on captive animals.

Weaknesses

Despite the potential GHG benefits of producing cultivated meat under optimal efficiency and powered by renewables, according to UNEP reporting, should production fall short of these circumstances, the climatic impact could be greater than that of producing conventional meat (UNEP, 2023). In a scenario where cultivated meat offers a mix of environmental benefits and drawbacks, such as increased water and land efficiency but decreased GHG efficiency, it may burden future policymakers with having to prioritize certain environmental interests over others when formulating decisions concerning the support of cultivated meat production systems. For instance, should prevailing stakeholders favor mitigating carbon emissions over preventing biodiversity loss associated with land use change, cultivated meat may not remain viable in jurisdictions where renewables cannot adequately supply the necessary energy inputs or if the technology exists in stage of development that does not yet provide a sufficient level of production efficiency.

UNEP reports that consumers primarily make food choices according to the parameters of cost and taste (UNEP, 2023; International Food Information Council, 2023). Thus far, the cost of producing cultivated meat has exceeded that of conventional meat on a per kilogram basis, which is perhaps to be expected for a novel production method (UNEP, 2023). Assuming significant technological leaps, Garrison et al. (2022) projected that cultivated meat from a "large-scale" facility could cost as much as $63 per kilogram. For this to occur, the researchers suggest that several technical milestones need to be reached, including low-cost hormones and more efficient culture media (UNEP, 2023; Garrison et al., 2022). For a more pragmatic projection, they find that a large-scale facility could produce cultivated hamburger meat which could exceed $100 per kilogram (Garrison et al., 2022). Garrison et al. (2022) assert that at such a high cost to consumers, cultivated meat would be inaccessible to many.

However, not all assessments of future cost concur. The UNEP report cites a projection that the production cost of cultivated meat could reach competitiveness "with some conventional meats by 2030 and serve as an affordable ingredient for plant-based and cultivated meat blends" (UNEP, 2023). In order to attain this status, it will be necessary to innovate on several fronts to improve efficiency, namely improved cell lines, culture media, scaffolding, and process design, as well as greatly expand productive capacity (UNEP, 2023).

Opportunities

Future progress in cultivated meat technology could offer a number of unique opportunities. This report highlights two: novel products and protein for long-term space missions.

Thus far, cultivated meat companies have primarily focused on commercializing products derived from traditional, widely consumed livestock animals such as cows and chickens. In order to minimize hurdles to public acceptance or avoid excessive regulatory burdens on the path to government approval, producing familiar products would seem to be a pragmatic approach in these early stages of technological development. However, in a future where societies embrace cultivated meat as a viable replacement for conventional meat, producers may no longer need to limit themselves to common livestock animals.

In 2023, Australian cultivated meat company, Vow, exhibited a “mammoth meatball,” created by culturing sheep myoblasts spliced with woolly mammoth DNA that codes for myosin, a protein partially responsible for meat’s flavor (Carrington, 2023). Though intended for demonstration rather than consumption, the mammoth meatball, in amalgamating an extinct elephantid with an extant, domesticated bovid, implies an incredibly wide range of possibilities for novel meat products in the future (Carrington, 2023).

This means that, from a technical perspective, animals currently unamenable to conventional meat production methods could still find their way to dinner plates through cellular cultivation. Take for instance, giraffes, the largest and longest gestating ruminants, a grouping that also includes common red meat livestock like cattle and sheep (Encyclopedia of Life, n.d.). Due to their appreciable size and rearing requirements, farming and slaughtering giraffes on a large scale for meat would likely be infeasible. Cultivated meat technology could bypass many of these logistical barriers to offer consumers unique culinary experiences (Bhat et al., 2019; Zaraska, 2013). Given the novelty of such products, perhaps companies could offer them at premium prices which might help offset high production costs?

Presently, in Southern and Eastern Africa, trophy hunting for wildlife is practiced as a tool for conservation, where tourists can pay fees to remove less desirable animals from the local population (Muposhi et al., 2017; Lindsey et al., 2007). These enterprises are relatively lucrative and appear to be increasing in popularity across Sub-Saharan Africa, even as their sustainability and effectiveness remain subject to debate (Muposhi et al., 2017; Lindsey et al., 2007).

With cultivated meat, new models for conservation and wildlife education could open, where consumers pay to dine on novel items such as giraffe burgers or penguin nuggets (Bhat et al., 2019; Zaraska, 2013). As discussed earlier, the biopsies involved in the cultivated meat production process are minimally invasive procedures and thus could potentially occur alongside routine veterinary activities that already take place in zoos and aquaria (Carpenter et al., 2016).

As the scope of species acceptable for cultivation widens, one may naturally consider the possibility of cultivating meat from human beings (Schaefer & Savulescu, 2014). In countries and jurisdictions without explicit laws against human meat consumption, such as the United States (except the state of Idaho), laws forbidding murder and the desecration of corpses have hitherto precluded the act as a legal possibility, regardless of the consent of any involved parties (Legal Information Institute, 2022; Schaefer & Savulescu, 2014). However, in theory, cultivated meat technology could generate human-derived food products without causing death or violating a person's remains (Locarno, 2023; Schaefer & Savulescu 2014).

While eating cultivated human meat may satisfy the dictionary's definition for cannibalism, in terms of production, the process could be said to resemble blood or organ donations (Oxford English Dictionary, 2023a; Locarno, 2023). In the US, the National Organ Transplant Act of 1984 makes the selling and buying of human organs and tissues illegal (Cohen, 2012). This, however, has not entirely halted the commodification of certain human tissues and cell lines. The case of Henrietta Lacks, a cervical cancer patient who succumbed to her illness in the early 1950s, well illustrates this point (Lucey et al., 2009).

While under care at Johns Hopkins Hospital, researchers observed that Lacks' biopsied cancer cells could survive and proliferate quickly outside of the human body (Beskow, 2016). Described as "immortal," these HeLa cells, named for the first two letters of Lacks' first and last names, in effect became the first human cell line (Lucey et al., 2009). Since their discovery, HeLa cells have been continually cultured and deployed in a wide array of biomedical applications, from development of vaccines for diseases like polio to studies concerning the effects of zero gravity on human cells in outer space (Lyapun et al., 2019).

The initial sample of what would become HeLa cells were sampled without Lacks' knowledge, and later, descendant cells would be commercialized by for-profit, biotechnology companies, like Thermo Fisher Scientific (Beskow, 2016; Holpuch, 2023; Thermo Fisher Scientific, 2024). It was not until 2023, over seven decades after Lacks' passing, that her family received compensation through an out-of-court settlement (Holpuch, 2023). Thermo Fisher continues to sell HeLa cells. As of May 2024, the company website lists a quantity of 3×10^6 "T-REx ™-HeLa" cells (R71407) for $2,545, demonstrating commercial availability of human cell lines (Thermo Fisher Scientific, 2024).

The case of HeLa cells shows that legal markets already exist for human cell lines and that companies are theoretically capable of cooperating with the donor (or other appropriate authority) to provide payment for them. Therefore, barring explicit bans on the practice, in the future, a market could emerge for cultivated human meat, particularly in countries that do not have laws that precisely forbid human cannibalism. Given the ubiquity of celebrity endorsements, perhaps in the future, consumers will have access to cultivated meat from select public figures (Knoll & Matthes, 2017).

Another, and perhaps less controversial, opportunity for cultivated meat in the future is as a high quality protein source for long duration space missions. As a determinant of health, food is also a critical contributor to the success of crewed space missions because deficiencies in nutrition could impede astronauts' performance (Cooper et al., 2011). Due to the unique circumstances of the operating environment, astronauts currently onboard the International Space Station (ISS) depend on regular but infrequent shipments from Earth to meet nutritional needs (Cooper et al., 2011).

Further, the provisions that they do receive must conform to several important limitations of the ISS, notably a lack of storage, refrigeration, preparation areas, or crew time (Cooper et al., 2011). In order to ensure food safety in such an environment, food items are typically single-serving and subject to preservation techniques such as thermostabilization, irradiation, and dehydration which may "reduce the quality of the food, including nutritional content and acceptability" (Cooper et al., 2011).

As NASA and its partners look to establish a long-term presence around Mars in the next decade, it will be important to reconsider extraterrestrial food systems (Douglas et al., 2020). A spacecraft launched today carrying food could reach the ISS in as little as four hours (NASA, 2024). For Mars, the same journey will last six months, necessitating technologies that "enable the crew to be self-sufficient and less dependent on resupply missions" (Cooper et al., 2011).

This makes designing an appropriate food system a difficult problem because preserved elements will need to be at once safe for human consumption, stable for at least five years under the hostile conditions of interplanetary space travel, palatable in a manner conducive to health and morale, nutritious, resource-minimizing, variable in terms of texture and flavor, reliable, usable, and suitable for space-ready appliances (Douglas et al., 2020).

Speaking to the issue of variety, Douglas et al. (2020) highlight that it may be necessary for food systems for long-term space missions to combine prepackaged items with "grown" elements to "avoid menu fatigue." In pursuit of overcoming barriers to providing future astronauts dietary protein of sufficient quality and form, the European Space Agency (ESA) sponsored two projects that probed the viability of cultivated meat in space (ESA, 2023). In theory, cultivated meat produced in the space environment could avoid the some of the problems of shelf-life while helping fulfill the parameters of palatability, nutritional quality, and as already mentioned, variety. In a 2023 press release, ESA reports that both projects yielded encouraging results for cultivated meat as a space-based protein solution and calls for additional research (ESA, 2023).

In the future, should humanity cement a permanent presence on or around extraterrestrial bodies, cultivated meat may play an integral role in facilitating protein security for long-term space explorers.

Threats

From a technical perspective, a primary threat to cultivated meat would be the inability to scale processes to a level appropriate for commercialization. UNEP describes at least four technological advancements necessary before achieving mass availability and access to cultivated meat in the general market. First, cell lines from various species need to exhibit an array of features amenable to cultivation in terms of proliferation and differentiation (UNEP, 2023). Cell lines that do not sufficiently proliferate in a suitable timeframe or reliably differentiate into the required cell types hinder efficiency of production processes (UNEP, 2023). Additionally, the cells must remain resilient to the stress involved in culturing (UNEP, 2023). For mammalian cells in large bioreactors, this could spell trouble. Firms may struggle to scale up capacity due to the fragility of mammal cells in the harsh conditions associated with stirring in larger bioreactors (Ye et al., 2022). This could mean that to meet future demand, a larger number of smaller, less efficient vessels will be needed (Ye et al., 2022). Should this inefficiency lead to higher costs or GHG emissions, cultivated meat could struggle to gain acceptance among the public or policymakers.

Second, UNEP argues that to be scalable, the culture media that supplies cells vital nutrients and hormones will require innovation (UNEP, 2023). Presently, cultivated meat production systems rely on fetal bovine serum as the culture medium which remains expensive, suboptimal for meat cultivation, and carries animal welfare concerns (UNEP, 2023). In order to deploy widely, UNEP maintains that culture media should be “low cost, animal ingredient-free, food-grade and food-safe” and capable of “[regulating] large-scale cell proliferation and differentiation” (UNEP, 2023). Limited progress has been achieved in meeting some of these standards, nonetheless, it is difficult to assume that any imagined technological development is guaranteed (UNEP, 2023). Should producers fail to deliver culture media of adequate efficiency, cultivated meat may remain prohibitively expensive for typical consumers (UNEP, 2023).

Third, current scaffolding materials which are required to achieve textures and structures comparable to conventional meat have not yet been perfected (UNEP, 2023; Ye et al., 2022). Identifying a scaffold capable of replicating the structure of conventional meat that is also safe when ingested and inexpensive remains an important element and limiting factor of the mass market deployment of cultivated meat (UNEP, 2023; Ye et al., 2022). In addition to texture and structure, obtaining the right color, flavor, and nutritional profiles will be paramount to cultivated meat’s success (Ye et al., 2022). Although food additives could help in these areas, their overuse could stoke hesitation or resistance among government regulators or the public (Ye et al., 2022). Thus, manufacturers may have to approach the challenge of incorporating these sensory elements through improvements in technique rather than through extraneous enhancements, which could prove to be a major impediment (Ye et al., 2022).

Fourth, the UNEP report points to production process design as a technical area that will require additional work (UNEP, 2023). As the technology is still in its early stages of development, industry players have yet to demonstrate models of production that can deliver in a manner that is competitive with conventional meat systems (UNEP, 2023). Being a new platform for meat production, certifying safety may introduce an entire family of additional constraints (Ye et al., 2022). Manufacturers will have to demonstrate safety for all input materials and methods, some of which may lack any history of use in commercial food products (Ye et al., 2022). Should companies fail to optimize production processes at scale and in a way that guarantees a minimum standard of safety, mass uptake may not be realized (Ye et al., 2022).

Even assuming complete technical success where cultivated meat is at once scalable, affordable, safe, and equivalent to conventional meat in terms of color, flavor, and nutritional quality, the issues of social and political acceptance may serve as the ultimate threats. Consider the matter of religious influence on diet discussed in the previous section. Do cultivated meat products conform to the dietary codes held by observant Muslims and Jews?

An Islamic advisory group working for the American company, GOOD Meat, found that cultivated meat could be considered halal assuming it originates from a permissible animal that has been slaughtered in manner conforming to Islamic practice and where the cultured cells have not been proliferated using proscribed substances such "as spilled blood, alcohol or materials taken from animals that have not been slaughtered properly or pigs" (Carballo, 2023).

In 2023, the largest kosher-certifying organization, Orthodox Union Kosher, gave its approval to an Israeli cultivated meat producer which was able to sidestep religious slaughter standards by proliferating its cell lines from a fertilized egg rather than a biopsy from a fully developed animal (Carballo, 2023). While these examples demonstrate a degree of acceptance from religious authorities, it remains to be seen how various religious segments of the global public will engage with cultivated meat products in a future of widespread availability and access.

Outside of religion, UNEP cites evidence that willingness to try cultivated meat presently differs between men and women, with women being more adverse (UNEP, 2023; Rombach et al., 2022). While UNEP notes that women are more willing to consume cultivated meat when informed that it carries potential safety benefits, this in itself does not entirely rule out the possibility of future resistance to uptake based on sex, gender, or some other form of identification (UNEP, 2023; Piochi et al., 2022).

In the political sphere, two opposing camps of stakeholders have already taken shape in the United States centered on a debate over labeling and disclosure for cultivated meat (Spring & Bence, 2022). In one camp sits the livestock farmers, meat companies and trade organizations, as well as the state governments for which these actors represent a substantial portion of the state economy (Spring & Bence, 2022). This adversarial camp, coalescing on the premise of protecting consumers from confusion, generally supports regulation and legislation limiting the language and terminology pertaining to meat products, both cultivated and conventional (Spring & Bence, 2022).

Opposite sits players in the meat alternative industry as well as activists who view cultivated meat as a remedy for the negative impacts associated with conventional meat (Spring & Bence, 2022). Hoping to compete head-to-head with conventional meat producers without the burden of using unfamiliar terms or language, this camp, on the premise of free expression, maintains that restrictions on labeling are unfair and may induce confusion through the mandated use of non-traditional language for cultivated products that are dietarily and culinarily equivalent to conventional products (Spring & Bence, 2022).

Safety and transparency issues take center stage in food regulation, and this proxy battle over consumer confusion pertains to the latter (Spring & Bence, 2022). In order to better appreciate the issue of political acceptance, this report will now examine cultivated meat through the lens of burgeoning policy in the United States.

Burgeoning Policy in the United States

A cursory glance would suggest that oversight for cultivated meat production and distribution falls under the overlapping responsibilities of the Department of Agriculture (USDA) and the Department of Health and Human Services (HHS) (GAO, 2020). Indeed, both departments exercise regulatory authority to ensure food products in the United States remain free of adulterants and bear truthful, transparent labeling (GAO, 2020; Spring & Bence, 2022).

Directed by the Federal Meat Inspection Act (FMIA) and the Poultry Products Inspection Act (PPIA), the USDA, through its Food Safety Inspection Service (FSIS), traditionally oversees ASFs produced from cattle, swine, and poultry (Spring & Bence, 2022). HHS, empowered by the Federal Food, Drug, and Cosmetic Act (FDCA), the Public Health Service Act (PHSA), and the Fair Packaging and Labeling Act (FPLA), addresses regulatory concerns for all other food categories through the Food and Drug Administration (FDA) (Spring & Bence, 2022). Nevertheless, when looking at conventional meat products, the picture of regulation and agency jurisdiction can still appear somewhat unclear. Classified apart from other foods derived from animal tissues, seafood products such as fish are regulated by the FDA rather than FSIS (FDA, 2024). Yet, catfish and all other Siluriformes represent a prominent exception to this rule, subject to FSIS jurisdiction (FSIS, 2020).

As cultivated meat constitutes a new technology and platform for producing meat, several questions emerged surrounding the appropriate division of regulatory roles between HHS and USDA. For instance, the FMIA officially describes meat as a food product sourced “wholly or in part from… or other portion of the carcass of” amenable species, implying that the original animal, by definition, is deceased before harvesting (Legal Information Institute, n.d., 21 U.S. Code § 601). Given that cells cultivated into viable meat products may originate in samples taken from living animals, does this suggest that FDA, rather than FSIS, has an exclusive claim to regulation? However, if at the time of sale, cultivated meat products are dietarily identical to, or indistinguishable from, their conventional counterparts, perhaps their mode of production is beside the point and the USDA should continue business as usual? Considering the high level of biotechnical complexity involved in the production of cultivated meat, which may closer resemble that of pharmaceuticals, is it optimal for the USDA to oversee a manufacturing process beyond the scope of their current expertise when another, more experienced agency exists?

Here, proponents for the FDA could assert that under the FDCA, the administration has the exclusive duty to regulate any “instrument, apparatus, implement, machine, contrivance, implant, in vitro reagent, or other similar or related article including any component, part, or accessory” related to the culturing of animal cells (Spring & Bence, 2022; Legal Information Institute, n.d., 21 U.S. Code § 321). In this context, given the complex production process involved in cultivated meat, any lack of FDA involvement begins to seem untenable.

Following a discussion period which sought to resolve these ambiguities and delineate the appropriate regulatory responsibilities of each party, in March of 2019, the agencies released the Formal Agreement Between FDA and USDA Regarding Oversight of Human Food Produced Using Animal Cell Technology Derived from Cell Lines of USDA-amenable Species (Benson & Greene, 2023; Spring & Bence, 2022; GAO, 2020). For meat types covered under the FMIA and PPIA, this landmark statement demarcates cultivated meat production at the harvest phase, where FDA will regulate all pre-harvest activities and FSIS will take reign in the post-harvest (Benson & Greene, 2023; Spring & Bence, 2022). For cultivated seafood, except for Siluriformes, the FDA will exert complete regulatory authority in all phases (Benson & Greene, 2023; Spring & Bence, 2022; GAO, 2020).

The agreement outlines these intentions with greater specificity in the fourth section, “Substance of the Agreement” (FDA, 2019). FDA will oversee production media and processes, manufacturing controls, tissue sampling, cell lines and storage, and inputs for proliferation or differentiation leading up to harvest by way of premarket consultations, direct guidance, and inspections (FDA, 2019; Benson & Greene, 2023). Further, FDA will verify compliance with Current Good Manufacturing Practices (CGMPs) to prevent adulteration, which are presently used in pharmaceuticals regulation (FDA, 2019; Benson & Greene, 2023).

In accordance with FMIA and PPIA, at the harvest phase, FSIS will assess cultivated tissues to ensure suitability for processing into food for human consumption (FDA, 2019; Benson & Greene, 2023). Additionally, FSIS will inspect the sites where cell lines are “harvested, processed, packaged or labeled” to prevent any adulteration or misbranding (FDA, 2019). As they will oversee the consumer-facing side of cultivated meat, FSIS will regulate labeling requirements on an as needed basis or as otherwise stipulated by law (FDA, 2019; Benson & Greene, 2023).

The regulators round out their responsibilities with the unresolved topics of labeling and safety, announcing an interagency intention to develop labeling principles to ensure consistency and transparency as well as an ad hoc cooperative effort to investigate “food safety issues involving products of cell-culture technology, derived from USDA-amenable species and required to bear a USDA mark of inspection” (FDA, 2019). While questions around safety may seem most obvious and pressing as a public concern, the issue of labeling has quickly formed a major battleground on which competing stakeholders fight.

In 2021, the FSIS opened to public comment the topic of cultured meat labeling for amenable species through an advance notice of proposed rulemaking (ANPR), where among other things, the FSIS sought input on a possible "standard of identity" which "[ensures] such products have the characteristics expected by consumers" through "specific names, terms, and information to be used on product labels" (FSIS, 2021). If provided a standard of identity, cultivated meat could also be subject to regulations related to formulation and modes of production and preparation (FSIS, 2021). Without a standard of identity, the USDA states that a food product (FSIS, 2021):

> "is misbranded unless its label bears the common or usual name of the food, if there is one, and the common or usual name of its ingredients (21 U.S.C. 601(n)(9) and 453(h)(9)). Common or usual names are generally established by common usage but, in some cases, they may be established by regulation. In the absence of either a standard of identity or appropriate common or usual name, the product must be identified by a descriptive name (9 CFR 317.2(e) and 381.117(a))."

The ANPR followed competing petitions submitted to FSIS from the United States Cattlemen's Association (USCA), an organization adversarial to cultivated meat, and the Harvard Law School's Animal Law & Policy Clinic, a group supportive of the technology (Benson & Greene, 2023; Spring & Bence, 2022). The USCA sought to tighten the definition of beef to include only products derived from traditionally reared cattle to the exclusion of alternatives, including but not limited to cultivated beef (FSIS, 2021; Spring & Bence, 2022).

Conversely, the Animal Law & Policy Clinic invoked the First Amendment in its petition, advising FSIS to avoid proscribing commonly used meat terminology for cultivated products in the market, and instead only mandate disclosures of cultivated origins in cases where consumers would face a heightened risk from ingestion (FSIS, 2021; Spring & Bence, 2022). After review of ANPR comments, the FSIS committed to evaluating cultivated meat labeling but rejected the USCA's call for a more definitions for the terms "meat" and "beef" (Spring & Bence, 2022).

In November of 2022, the FDA announced the completion of its first pre-market consultation for cultivated chicken produced by the firm UPSIDE Foods (FDA, 2022). The FDA emphasized the voluntary nature of the consultation, noting that it did not constitute an approval process, rather that the firm had ratified all questions relevant to safety (FDA, 2022). In the summer of 2023, UPSIDE obtained a grant of inspection from the USDA, permitting the sale of its products across the country in a first for cultivated meat (Good Food Institute, 2023).

Despite this apparent victory for cultivated meat at the federal level, the technology has faced greater hostility at the state level. Since 2018, at least sixteen additional states have passed pieces of legislation that tightens regulations on meat labeling in response to cultivated meat, according to the National Agricultural Law Center at the University of Arkansas (2024).

Table 13 lists these states, their corresponding legislation, and the main political party (partisanship) associated with that legislation as reported in the LegiScan (n.d.) database.

Table 13: State Legislation Restricting Cultivated Meat Labeling

State	Date	Legislation	Partisanship
Alabama	May 2019	H.B. 518	Republican
Arkansas	March 2019	H.B. 1407	Republican
Georgia	December 2020	S.B. 211	Republican
Kansas	May 2022	S.B. 261	Committee
Kentucky	March 2019	H.B. 311	Republican
Louisiana	June 2019	S.B. 152	Republican
Maine	June 2019	H.B. 351	-
Mississippi	March 2019	S.B. 2922	Republican
Missouri	June 2018	S.B. 627	Republican
Montana	March 2019	H.B. 327	Republican
North Dakota	March 2019	H.B. 140	Republican
Oklahoma	May 2020	H.B. 306	Republican
South Carolina	May 2019	H. 4245	Republican
South Dakota	March 2019	S.B. 68	Republican
Texas	May 2023	S.B. 664	Republican
Wyoming	January 2018	S.B. 68	Republican
Sources: National Agricultural Law Center (2024); LegiScan (n.d.)			

Recently, some states are attempting more aggressive measures to curb the future adoption of cultivated meat. In May of 2024, Florida's governor signed legislation that outright prohibits the sale of cultivated meat within state borders (S.B. 1084), in a press release citing a motivation "to stop the World Economic Forum's goal of forcing the world to eat lab-grown meat and insects" (Searcey, 2024; Office of Governor Ron DeSantis, 2024). The association between cultivated meat and supposed despotism continues: "Today, Florida is fighting back against the global elite's plan to force the world to eat meat grown in a petri dish or bugs to achieve their authoritarian goals" (Office of Governor Ron DeSantis, 2024).

Under Florida's ban, violators could face up to about two months of jail time (Searcey, 2024). Shortly after, Alabama's S.B. 23 received the governor's signature, forbidding the production or distribution of cultivated meat, under penalty of up to three months of jail time (Reynolds, 2024). Alabama's restrictions spare governments, institutions of higher education, and their collaborators from conducting research on cultivated meat (Alabama Legislature, 2024). Other states are slated to follow Florida and Alabama's lead in this new wave of administrative hostility to cultivated meat. At the time of writing, similar legislative initiatives are being considered in Arizona and Tennessee (Nowell, 2024).

Of states that have proposed, passed, or enacted restrictions on cultivated meat, whether in labeling or sale, the overwhelming majority have been Republican-led efforts (

Table 13). Assuming this trend of politically motivated restrictions persist unchallenged, and should cultivated meat eventually become scalable, the US may host two parallel realities for policy regarding cultivated meat; one with familiar regulatory structures adapted from conventional meat and one where conventional meat is the only legal option for consumers.

Summary and Recommendations

This report sought to better understand future challenges concerning protein food and evaluate the two proposed mitigation strategies of dietary change and cultivated meat. It finds that, as a category, protein food is uniquely valuable for human nutrition. However, under current patterns of production and consumption, it also finds that animal sources of protein are uniquely harmful to the global environment and threatening to public health.

The EAT-Lancet Commission calls for urgent dietary change, which generally involves substantial reductions in red meat and increases in plant protein consumption (Willett et al., 2019). Modeling for various protein foods' availability in 2050 reveals that most of the world will have excessive and unsustainable red meat supplies as well as inadequate plant protein supplies relative to EAT-Lancet's dietary recommendations for a world bearing 10 billion inhabitants.

Organizations like the United Nations Environmental Programme have discussed cultivated meat, which permits the production of animal source foods without mass rearing and slaughter, as a potential solution (UNEP, 2023). A high level SWOT analysis reveals that cultivated meat could deliver significant environmental and public health benefits, but without overcoming key technical and political barriers, will remain small-scale and prohibitively expensive for the foreseeable future.

In light of these findings, this report recommends the following policy objectives for national governments, in general:

1. Increase plant protein production or imports in a sustainable manner.

2. Encourage reductions in, but not the elimination of, red meat consumption.

3. Financially, support research that enables scalability in cultivated meat, namely resilient cell line development, affordable culture media, and edible scaffolding.

For the United States, in particular, this report makes the following policy recommendations:

1. Direct the HHS and USDA to perennially consider cultivated meat FBDGs.

   Every five years the HHS and USDA should form an independent advisory committee composed of experts that review the latest scientific knowledge concerning diet and nutrition for the purpose of informing changes to its FBDGs. This report recommends that future committees have at least one expert on cultivated meat and that the committee will be asked to evaluate cultivated meat's safety and ability to supply adequate nutrition. Doing so will accomplish two goals. First, it will demonstrate to the American public a governmental commitment to transparency and accountability when it comes to cultivated meat technology. Second, it will produce insights for future FBDGs and regulations to help ensure that cultivated meat products continue to meet or exceed the safety and benefits of conventional meat.

2. Direct the FDA to form an independent advisory committee for CGMPs for cultivated meat.

   As discussed in the section concerning the federal approach to cultivated meat, the FDA intends to regulate production processes using CGMPs as they do now with pharmaceuticals. Given the novelty of cultivated meat and the political and cultural sensitivity surrounding food, this report recommends that the FDA form an independent advisory committee every five years to evaluate CGMPs specifically as they relate to cultivated meat production, in order to produce a technical knowledge update for FDA regulatory officials to review. This too will accomplish two goals. First, it will demonstrate to the American public that the federal government has a long-term interest in constant improvement of the production process for cultivated meat- and in a manner that emphasizes any meaningful differences between CGMPs for food and pharmaceuticals. Second, it will allow the FDA to keep abreast of technical advancements pertinent to safety and efficiency of cultivated meat production so that it may encourage consistent innovation in firms over time.

3. Direct the FDA and FSIS to convene on a regular schedule to compare notes on post-harvest regulation.

   Given that the FDA and FSIS will have split responsibilities when it comes to regulating cultivated meat in the post-harvest phases, where FDA will oversee all non-Siluriformes seafood species, this report recommends that the two agencies convene on a regular schedule, of at least every five years, for the express purpose of sharing successes and failures of their independent regulatory practices. This recommendation would permit continued respect for agency jurisdiction, and at the same time, facilitate information exchange that promotes adaptation over time in a way that imitates a natural experiment.

4. Allow states to regulate their own cultivated meat labeling.

   Given that at least sixteen states have already demonstrated an interest in regulating cultivated meat labels, this report recommends that, for now, the federal government refrain from proscribing state-level labeling. Instead, the federal government should look to these state-level initiatives as natural experiments from which to glean insights. This report recommends that HHS and USDA schedule a systematic look-back of at least every five years from the launch of the first cultivated meat product available to the general public. This look-back would evaluate the economic and social consequences of the states' labeling requirements or lack thereof. Only then should the federal government consider enforcing nationwide labeling standards.

5. Direct the Environmental Protection Agency to conduct an environmental impact assessment of cultivated meat on a regular schedule.

   Given that the deleterious effects of conventional meat on the environment provide much of the justification for developing and deploying cultivated meat, it would behoove the federal government to evaluate to what extent these products are successful in mitigating environmental harm and natural resource depletion. To that end, this report recommends that the United States Environmental Protection Agency assemble an independent panel of experts to conduct a formal review of cultivated meat's impact on a schedule of at least every five years.

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Appendix

Appendix A: Member States of the UN with FAO Subregion and 2050 Religion

Code	UN Member State	FAO Subregion	Religion
AFG	Afghanistan	Southern Asia	I
AGO	Angola	Middle Africa	-
ALB	Albania	Southern Europe	I
AND	Andorra	Southern Europe	-
ARE	United Arab Emirates	Western Asia	I
ARG	Argentina	South America	-
ARM	Armenia	Western Asia	-
ATG	Antigua and Barbuda	Caribbean	-
AUS	Australia	Australia and N.Z.	-
AUT	Austria	Western Europe	-
AZE	Azerbaijan	Western Asia	I
BDI	Burundi	Eastern Africa	-
BEL	Belgium	Western Europe	-
BEN	Benin	Western Africa	-
BFA	Burkina Faso	Western Africa	I
BGD	Bangladesh	Southern Asia	I
BGR	Bulgaria	Eastern Europe	-
BHR	Bahrain	Western Asia	I
BHS	Bahamas	Caribbean	-
BIH	Bosnia and Herzegovina	Southern Europe	-
BLR	Belarus	Eastern Europe	-
BLZ	Belize	Central America	-
BOL	Bolivia (Plurinational State of)	South America	-
BRA	Brazil	South America	-
BRB	Barbados	Caribbean	-
BRN	Brunei Darussalam	Southeastern Asia	I
BTN	Bhutan	Southern Asia	-
BWA	Botswana	Southern Africa	-
CAF	Central African Republic	Middle Africa	-
CAN	Canada	Northern America	-
CHE	Switzerland	Western Europe	-

CHL	Chile	South America	-
CHN	China	Eastern Asia	-
CIV	Côte D'Ivoire	Western Africa	-
CMR	Cameroon	Middle Africa	-
COD	Democratic Republic of the Congo	Middle Africa	-
COG	Congo	Middle Africa	-
COL	Colombia	South America	-
COM	Comoros	Eastern Africa	I
CPV	Cabo Verde	Western Africa	-
CRI	Costa Rica	Central America	-
CUB	Cuba	Caribbean	-
CYP	Cyprus	Western Asia	-
CZE	Czechia	Eastern Europe	-
DEU	Germany	Western Europe	-
DJI	Djibouti	Eastern Africa	I
DMA	Dominica	Caribbean	-
DNK	Denmark	Northern Europe	-
DOM	Dominican Republic	Caribbean	-
DZA	Algeria	Northern Africa	I
ECU	Ecuador	South America	-
EGY	Egypt	Northern Africa	I
ERI	Eritrea	Eastern Africa	-
ESP	Spain	Southern Europe	-
EST	Estonia	Northern Europe	-
ETH	Ethiopia	Eastern Africa	-
FIN	Finland	Northern Europe	-
FJI	Fiji	Melanesia	-
FRA	France	Western Europe	-
FSM	Micronesia (Federated States of)	Micronesia	-
GAB	Gabon	Middle Africa	-
GBR	United Kingdom of Great Britain and Northern Ireland	Northern Europe	-
GEO	Georgia	Western Asia	-
GHA	Ghana	Western Africa	-
GIN	Guinea	Western Africa	I
GMB	Gambia (Republic of The)	Western Africa	I
GNB	Guinea Bissau	Western Africa	-

GNQ	Equatorial Guinea	Middle Africa	-
GRC	Greece	Southern Europe	-
GRD	Grenada	Caribbean	-
GTM	Guatemala	Central America	-
GUY	Guyana	South America	-
HND	Honduras	Central America	-
HRV	Croatia	Southern Europe	-
HTI	Haiti	Caribbean	-
HUN	Hungary	Eastern Europe	-
IDN	Indonesia	Southeastern Asia	I
IND	India	Southern Asia	H
IRL	Ireland	Northern Europe	-
IRN	Iran (Islamic Republic of)	Southern Asia	I
IRQ	Iraq	Western Asia	I
ISL	Iceland	Northern Europe	-
ISR	Israel	Western Asia	J
ITA	Italy	Southern Europe	-
JAM	Jamaica	Caribbean	-
JOR	Jordan	Western Asia	I
JPN	Japan	Eastern Asia	-
KAZ	Kazakhstan	Central Asia	I
KEN	Kenya	Eastern Africa	-
KGZ	Kyrgyzstan	Central Asia	I
KHM	Cambodia	Southeastern Asia	-
KIR	Kiribati	Micronesia	-
KNA	Saint Kitts and Nevis	Caribbean	-
KOR	Republic of Korea	Eastern Asia	-
KWT	Kuwait	Western Asia	I
LAO	Lao People’s Democratic Republic	Southeastern Asia	-
LBN	Lebanon	Western Asia	I
LBR	Liberia	Western Africa	-
LBY	Libya	Northern Africa	I
LCA	Saint Lucia	Caribbean	-
LIE	Liechtenstein	Western Europe	-
LKA	Sri Lanka	Southern Asia	-
LSO	Lesotho	Southern Africa	-

LTU	Lithuania	Northern Europe	-
LUX	Luxembourg	Western Europe	-
LVA	Latvia	Northern Europe	-
MAR	Morocco	Northern Africa	I
MCO	Monaco	Western Europe	-
MDA	Republic of Moldova	Eastern Europe	-
MDG	Madagascar	Eastern Africa	-
MDV	Maldives	Southern Asia	I
MEX	Mexico	Central America	-
MHL	Marshall Islands	Micronesia	-
MKD	North Macedonia	Southern Europe	I
MLI	Mali	Western Africa	I
MLT	Malta	Southern Europe	-
MMR	Myanmar	Southeastern Asia	-
MNE	Montenegro	Southern Europe	-
MNG	Mongolia	Eastern Asia	-
MOZ	Mozambique	Eastern Africa	-
MRT	Mauritania	Western Africa	I
MUS	Mauritius	Eastern Africa	-
MWI	Malawi	Eastern Africa	-
MYS	Malaysia	Southeastern Asia	I
NAM	Namibia	Southern Africa	-
NER	Niger	Western Africa	I
NGA	Nigeria	Western Africa	I
NIC	Nicaragua	Central America	-
NLD	Netherlands (Kingdom of the)	Western Europe	-
NOR	Norway	Northern Europe	-
NPL	Nepal	Southern Asia	H
NRU	Nauru	Micronesia	-
NZL	New Zealand	Australia and N.Z.	-
OMN	Oman	Western Asia	I
PAK	Pakistan	Southern Asia	I
PAN	Panama	Central America	-
PER	Peru	South America	-
PHL	Philippines	Southeastern Asia	-
PLW	Palau	Micronesia	-

PNG	Papua New Guinea	Melanesia	-
POL	Poland	Eastern Europe	-
PRK	Democratic People's Republic of Korea	Eastern Asia	-
PRT	Portugal	Southern Europe	-
PRY	Paraguay	South America	-
QAT	Qatar	Western Asia	I
ROU	Romania	Eastern Europe	-
RUS	Russian Federation	Eastern Europe	-
RWA	Rwanda	Eastern Africa	-
SAU	Saudi Arabia	Western Asia	I
SDN	Sudan	Northern Africa	I
SEN	Senegal	Western Africa	I
SGP	Singapore	Southeastern Asia	-
SLB	Solomon Islands	Melanesia	-
SLE	Sierra Leone	Western Africa	I
SLV	El Salvador	Central America	-
SMR	San Marino	Southern Europe	-
SOM	Somalia	Eastern Africa	I
SRB	Serbia	Southern Europe	-
SSD	South Sudan	Eastern Africa	-
STP	Sao Tome and Principe	Middle Africa	-
SUR	Suriname	South America	-
SVK	Slovakia	Eastern Europe	-
SVN	Slovenia	Southern Europe	-
SWE	Sweden	Northern Europe	-
SWZ	Eswatini	Southern Africa	-
SYC	Seychelles	Eastern Africa	-
SYR	Syrian Arab Republic	Western Asia	I
TCD	Chad	Middle Africa	I
TGO	Togo	Western Africa	-
THA	Thailand	Southeastern Asia	-
TJK	Tajikistan	Central Asia	I
TKM	Turkmenistan	Central Asia	I
TLS	Timor-Leste	Southeastern Asia	-
TON	Tonga	Polynesia	-
TTO	Trinidad and Tobago	Caribbean	-

TUN	Tunisia	Northern Africa	I
TUR	Türkiye	Western Asia	I
TUV	Tuvalu	Polynesia	-
TZA	United Republic of Tanzania	Eastern Africa	-
UGA	Uganda	Eastern Africa	-
UKR	Ukraine	Eastern Europe	-
URY	Uruguay	South America	-
USA	United States of America	Northern America	-
UZB	Uzbekistan	Central Asia	I
VCT	Saint Vincent and the Grenadines	Caribbean	-
VEN	Venezuela, Bolivarian Republic of	South America	-
VNM	Viet Nam	Southeastern Asia	-
VUT	Vanuatu	Melanesia	-
WSM	Samoa	Polynesia	-
YEM	Yemen	Western Asia	I
ZAF	South Africa	Southern Africa	-
ZMB	Zambia	Eastern Africa	-
ZWE	Zimbabwe	Eastern Africa	-

Appendix B: Food Information for Cost of Protein Adequacy Calculation

Item	FCT	FCT Code	FCT Name	Energy Density	Edible Portion	Notes
cbeef	USDA SR28	13795mod	BEEF,ALL GRADES,RAW	214	1.00	
cpork	USDA SR28	10972	PORK,GROUND,84% LN / 16% FAT,RAW	218	1.00	
clamb	USDA SR28	17001mod	LAMB,ALL GRADES,RAW	267	0.77	
cpoul	USDA SR28	5006	CHICKEN,BROILERS OR FRYERS,MEAT & SKN,RAW	215	0.68	
ceggs	USDA SR28	1123	EGG,WHL,RAW,FRSH	143	0.88	
cmilk	WA 2019	10_001	Milk, cow, whole, pasteurized or UHT, 3.5% fat	64	1.00	
cbean	USDA SR28	16014mod	BEANS,BLACK,MATURE SEEDS,RAW	340	1.00	modified by this study to include average all beans not used elsewhere in this table
cchkp	USDA SR28	16056	CHICKPEAS (GARBANZO BNS,BENGAL GM),MATURE SEEDS,RAW	378	1.00	
ccowp	WA 2019	03_005mod	Cowpea, black, dry, raw	319	1.00	modified by this study to include average across black brown and white variants
clent	USDA SR28	16069	LENTILS,RAW	352	1.00	
cpigp	USDA SR28	16101	PIGEON PEAS (RED GM),MATURE SEEDS,RAW	343	1.00	
copul	USDA SR28	16085	PEAS,GRN,SPLIT,MATURE SEEDS,RAW	352	1.00	
cgrnd	USDA SR28	16087mod	PEANUTS,ALL TYPES,RAW (shelled)	567	0.85	modified by this study to include average of shelled and unshelled variants
cgdml	WA 2019	06_027	Groundnut flour, with fat	579	1.00	
csoyb	WA 2019	03_008	Soya bean, dry, raw	381	1.00	
cothr	USDA SR28	12087mod	NUTS,CASHEW NUTS,RAW	609	1.00	cothr contains tree nuts; modified by this study to include average of cashews, walnuts, and almonds

Source: Food Prices for Nutrition (2023)

Appendix C: Protein Score Results, by Country (SSP1)

Country	Score	Red Meat	Poultry	Eggs	Dairy	Plant
AFG	1	4.44	0.19	0.26	1.06	0.04
AGO	0	3.58	0.54	0.25	0.20	0.15
ALB	1	4.17	0.92	1.19	3.48	0.16
AND	2	12.63	1.55	2.75	1.71	0.28
ARE	1	6.47	4.43	2.82	1.60	0.35
ARG	2	13.73	2.19	1.78	1.65	0.04
ARM	2	6.35	0.60	1.86	1.80	0.01
ATG	2	7.16	4.17	1.11	1.22	0.17
AUS	1	12.39	2.77	1.06	2.08	0.13
AUT	2	14.13	1.09	2.47	1.92	0.16
AZE	1	3.67	0.34	1.07	0.98	0.04
BDI	0	2.69	0.24	0.14	0.13	0.86
BEL	1	8.62	1.38	2.38	2.40	0.16
BEN	1	2.20	1.06	0.34	0.31	0.53
BFA	0	6.42	0.46	0.95	0.35	0.60
BGD	1	1.03	0.13	0.73	0.33	0.14
BGR	2	5.53	1.83	2.56	1.63	0.08
BHR	1	6.47	4.43	2.82	1.60	0.35
BHS	2	7.16	4.17	1.11	1.22	0.18
BIH	2	5.11	0.56	1.05	1.41	0.17
BLR	2	9.78	1.04	3.09	1.47	0.05
BLZ	1	4.43	2.87	0.80	1.00	0.31
BOL	1	8.46	2.12	1.14	0.36	0.19
BRA	1	9.00	3.01	1.46	2.09	0.33
BRB	2	7.16	4.17	1.11	1.22	0.19
BRN	1	1.54	2.50	2.91	0.97	-
BTN	0	2.75	0.07	0.18	0.54	0.29
BWA	1	3.69	0.32	0.51	1.03	0.19
CAF	0	14.61	0.43	0.13	0.45	0.16
CAN	1	8.22	2.53	2.19	1.80	0.27
CHE	1	14.54	0.84	1.89	2.59	0.16
CHL	1	10.05	2.42	1.32	0.94	0.12
CHN	0	15.46	1.00	4.15	0.90	0.30
CIV	1	1.54	0.27	0.55	0.29	0.20

CMR	0	3.04	0.41	0.19	0.29	0.47
COD	0	4.82	0.13	0.13	0.73	0.89
COG	2	1.75	1.18	0.22	0.29	0.15
COL	2	4.95	1.25	2.02	1.33	0.16
COM	2	1.94	2.21	1.81	0.74	0.18
CPV	2	19.46	2.76	1.80	1.05	0.15
CRI	3	3.87	1.58	1.98	1.78	0.30
CUB	2	5.00	1.22	1.60	0.74	0.51
CYP	3	9.13	1.74	1.90	1.75	0.18
CZE	3	9.79	2.00	1.84	1.90	0.12
DEU	0	10.83	0.90	2.28	2.35	0.14
DJI	0	6.30	0.76	0.14	0.71	0.04
DMA	2	7.16	4.17	1.11	1.22	0.17
DNK	1	12.72	1.27	3.99	2.20	0.08
DOM	1	3.92	2.33	1.28	0.55	0.18
DZA	2	3.26	0.63	1.04	1.21	0.15
ECU	2	7.37	2.07	1.15	1.06	0.08
EGY	1	3.01	1.07	0.80	0.43	0.26
ERI	0	4.12	0.18	0.27	0.48	0.37
ESP	2	12.63	1.55	2.75	1.71	0.33
EST	1	8.13	1.48	2.54	2.36	0.08
ETH	1	1.77	0.08	0.20	0.22	0.45
FIN	2	15.37	1.16	1.56	2.87	0.06
FJI	1	13.00	3.05	1.51	0.49	0.20
FRA	1	12.63	1.60	2.67	2.65	0.12
FSM	1	14.84	3.93	1.94	0.93	0.04
GAB	1	4.70	1.91	0.34	0.50	0.23
GBR	2	12.49	1.98	1.92	2.36	0.15
GEO	1	6.83	0.80	1.39	2.00	0.04
GHA	1	1.81	0.78	0.30	0.21	0.23
GIN	0	2.47	0.17	0.63	0.21	0.28
GMB	0	2.16	0.89	0.58	0.39	0.21
GNB	0	7.80	0.23	0.22	0.30	0.08
GNQ	0	0.40	0.07	0.44	-	-
GRC	2	10.47	1.13	1.85	2.69	0.27
GRD	2	7.16	4.17	1.11	1.22	0.16
GTM	1	2.54	1.70	3.42	0.56	0.27

GUY	0	2.11	2.43	0.55	0.88	0.14
HND	2	2.95	2.37	1.15	1.13	0.23
HRV	1	7.77	0.68	2.14	1.94	0.12
HTI	0	3.37	0.39	0.14	0.25	0.27
HUN	1	9.02	2.78	3.33	1.68	0.11
IDN	1	0.93	0.88	1.91	0.12	0.20
IND	0	0.41	0.41	0.79	0.89	0.26
IRL	2	12.15	1.81	1.34	2.77	0.10
IRN	2	3.49	1.35	1.93	0.73	0.23
IRQ	0	0.62	0.21	0.40	0.41	0.10
ISL	2	14.61	1.36	1.52	3.37	0.03
ISR	2	4.45	4.63	1.85	1.63	0.29
ITA	0	12.10	0.96	2.17	2.45	0.23
JAM	1	4.23	6.02	0.85	1.13	0.10
JOR	2	4.31	2.33	1.47	1.15	0.25
JPN	1	5.58	1.19	3.98	0.84	0.33
KAZ	2	6.81	1.03	1.35	2.31	0.02
KEN	0	4.14	0.14	0.56	0.87	0.36
KGZ	0	8.76	0.30	0.75	2.34	0.09
KHM	0	5.33	0.42	0.84	0.08	0.14
KIR	1	14.84	3.93	1.94	0.93	0.04
KNA	2	7.16	4.17	1.11	1.22	0.17
KOR	1	9.19	1.10	2.62	0.24	0.21
KWT	1	6.47	4.43	2.82	1.60	0.33
LAO	1	5.03	0.68	1.22	0.08	0.13
LBN	3	6.67	1.99	1.71	1.20	0.43
LBR	1	3.36	1.04	0.75	0.10	0.14
LBY	2	3.22	1.23	2.55	1.15	0.20
LCA	2	7.16	4.17	1.11	1.22	0.18
LIE	1	14.54	0.84	1.89	2.59	0.12
LKA	0	0.79	0.63	0.88	0.52	0.25
LSO	0	4.98	0.47	0.20	0.26	0.14
LTU	1	8.13	1.48	2.54	2.36	0.08
LUX	1	8.62	1.38	2.38	2.40	0.09
LVA	1	8.13	1.48	2.54	2.36	0.09
MAR	2	3.18	1.11	1.57	0.41	0.20
MCO	1	12.63	1.60	2.67	2.65	0.10

MDA	2	3.95	1.48	2.01	1.75	0.05
MDG	0	5.65	0.91	0.28	0.44	0.13
MDV	2	1.94	2.21	1.81	0.74	0.21
MEX	1	7.59	2.18	3.45	1.06	0.32
MHL	1	14.84	3.93	1.94	0.93	0.04
MKD	3	1.78	0.56	1.05	1.41	0.17
MLI	0	4.47	0.49	0.16	0.83	0.26
MLT	0	12.10	0.96	2.17	2.45	0.22
MMR	2	6.72	1.89	1.73	0.29	0.41
MNE	2	5.11	0.56	1.05	1.41	0.17
MNG	1	24.82	0.05	0.33	1.03	0.03
MOZ	0	9.89	0.18	0.19	0.07	0.17
MRT	1	6.07	0.28	0.61	1.38	0.25
MUS	1	2.94	2.21	1.81	0.74	0.19
MWI	0	3.24	0.15	0.44	0.12	0.43
MYS	1	1.76	2.91	3.14	0.71	0.11
NAM	1	5.90	1.00	0.39	0.79	0.15
NER	1	11.86	0.25	0.16	1.17	0.62
NGA	2	1.64	0.18	1.09	0.21	0.40
NIC	2	1.94	1.77	0.88	0.85	0.44
NLD	1	9.37	1.25	3.41	3.03	0.17
NOR	1	11.87	0.75	1.96	2.26	0.09
NPL	1	1.09	0.12	0.53	0.84	0.29
NRU	1	14.84	3.93	1.94	0.93	0.04
NZL	0	13.37	2.77	2.05	0.89	0.20
OMN	1	6.47	4.43	2.82	1.60	0.30
PAK	1	3.07	0.31	0.65	1.88	0.15
PAN	1	4.52	2.25	1.27	0.96	0.13
PER	3	1.78	1.10	1.12	0.56	0.16
PHL	1	9.91	0.78	1.50	0.18	0.09
PLW	1	14.84	3.93	1.94	0.93	0.04
PNG	0	12.66	0.23	0.57	0.00	0.04
POL	2	10.81	1.39	2.39	1.58	0.07
PRK	1	2.50	0.12	1.08	0.05	0.29
PRT	3	10.71	1.51	1.75	1.99	0.16
PRY	0	8.95	0.72	3.95	0.76	0.31
QAT	1	6.47	4.43	2.82	1.60	0.33

ROU	1	7.67	1.58	3.04	2.98	0.09
RUS	2	6.68	1.28	2.99	1.75	0.06
RWA	0	2.41	0.04	0.11	0.30	0.77
SAU	0	2.74	2.45	0.98	0.93	0.13
SDN	1	9.31	0.14	0.39	1.89	0.29
SEN	0	3.01	0.46	0.65	0.61	0.18
SGP	0	7.66	2.50	2.91	0.97	-
SLB	0	6.42	0.16	0.48	0.09	0.16
SLE	0	0.62	0.37	0.45	0.14	0.46
SLV	2	2.01	1.35	2.10	1.14	0.34
SMR	0	12.10	0.96	2.17	2.45	0.19
SOM	0	20.15	0.22	0.16	5.65	0.08
SRB	2	5.11	0.56	1.05	1.41	0.17
SSD	1	9.31	0.14	0.39	1.89	0.29
STP	2	19.46	2.76	1.80	1.05	0.15
SUR	0	2.11	2.43	0.55	0.88	0.15
SVK	2	7.36	1.37	2.59	1.07	0.09
SVN	2	10.76	1.37	1.27	2.21	0.13
SWE	0	9.99	0.90	2.14	3.15	0.11
SWZ	2	9.74	1.22	1.63	0.92	0.28
SYC	1	2.94	2.21	1.81	0.74	0.20
SYR	1	5.97	0.91	2.46	1.70	0.41
TCD	0	3.96	0.13	0.14	0.35	0.79
TGO	0	3.79	0.99	0.32	0.19	0.30
THA	1	7.86	1.31	3.39	0.27	0.15
TJK	0	3.67	0.12	0.26	0.82	0.04
TKM	2	12.57	0.29	1.61	1.78	0.01
TLS	0	7.53	0.89	0.37	0.09	0.24
TON	1	14.84	3.93	1.94	0.93	0.04
TTO	2	7.16	4.17	1.11	1.22	0.18
TUN	2	4.06	1.03	1.70	0.97	0.28
TUR	2	2.37	1.09	2.36	1.32	0.37
TUV	1	14.84	3.93	1.94	0.93	0.04
TZA	0	3.15	0.27	0.32	0.53	0.57
UGA	0	4.93	0.28	0.21	0.55	0.50
UKR	2	5.22	1.30	3.02	1.86	0.09
URY	2	10.34	1.06	2.19	1.39	0.07

USA	0	10.27	3.12	2.79	2.51	0.27
UZB	1	5.93	0.14	0.90	1.63	0.02
VCT	2	7.16	4.17	1.11	1.22	0.17
VEN	2	3.63	1.81	1.01	0.73	0.10
VNM	0	14.11	0.70	0.95	0.16	0.25
VUT	1	18.39	1.14	0.83	0.25	0.17
WSM	1	14.84	3.93	1.94	0.93	0.04
YEM	0	2.33	0.82	0.49	0.46	0.12
ZAF	1	8.53	2.27	1.20	0.80	0.10
ZMB	1	3.11	0.62	1.09	0.18	0.15
ZWE	0	9.13	0.81	0.46	0.43	0.33

Appendix D: Protein Score Results, by Country (SSP2)

Country	Score	Red Meat	Poultry	Eggs	Dairy	Plant
AFG	0	3.19	0.15	0.21	0.91	0.04
AGO	0	2.54	0.40	0.21	0.15	0.13
ALB	1	4.05	0.86	1.18	3.47	0.16
AND	2	12.72	1.55	2.81	1.70	0.27
ARE	1	6.40	4.40	2.77	1.58	0.35
ARG	2	13.79	2.13	1.77	1.63	0.03
ARM	2	5.69	0.51	1.82	1.77	0.01
ATG	2	6.38	3.74	1.02	1.22	0.17
AUS	1	12.17	2.71	1.08	2.06	0.13
AUT	2	14.33	1.11	2.52	1.93	0.15
AZE	1	3.37	0.30	1.06	0.97	0.04
BDI	1	1.84	0.15	0.11	0.10	0.74
BEL	1	8.77	1.41	2.42	2.41	0.15
BEN	1	1.52	0.79	0.26	0.23	0.46
BFA	0	4.51	0.32	0.76	0.29	0.55
BGD	0	0.79	0.12	0.58	0.28	0.12
BGR	2	5.40	1.74	2.56	1.63	0.08
BHR	1	6.40	4.40	2.77	1.58	0.34
BHS	2	6.38	3.74	1.02	1.22	0.17
BIH	2	5.01	0.53	1.05	1.41	0.16
BLR	1	9.63	0.99	3.05	1.48	0.05
BLZ	0	4.09	2.62	0.77	1.00	0.29
BOL	2	7.74	1.87	1.09	0.36	0.18
BRA	2	8.60	2.66	1.44	1.79	0.31
BRB	2	6.38	3.74	1.02	1.22	0.19
BRN	1	1.54	2.56	2.95	0.98	-
BTN	0	2.57	0.06	0.17	0.53	0.27
BWA	1	3.32	0.29	0.48	1.02	0.18
CAF	0	10.29	0.24	0.10	0.34	0.14
CAN	1	8.31	2.63	2.19	1.81	0.26
CHE	1	14.68	0.85	1.93	2.61	0.16
CHL	1	9.85	2.42	1.30	0.94	0.12
CHN	0	14.77	0.96	4.04	0.69	0.28
CIV	1	1.33	0.23	0.49	0.25	0.19

CMR	0	2.59	0.32	0.16	0.25	0.42
COD	0	3.08	0.08	0.10	0.52	0.76
COG	1	1.44	0.92	0.19	0.27	0.13
COL	3	4.74	1.20	1.96	1.34	0.15
COM	3	1.69	1.71	1.50	0.73	0.17
CPV	3	13.81	1.99	1.42	1.03	0.14
CRI	3	3.66	1.50	1.93	1.78	0.28
CUB	2	4.66	1.12	1.55	0.74	0.48
CYP	3	9.09	1.71	1.84	1.75	0.18
CZE	2	9.83	2.02	1.85	1.90	0.12
DEU	0	10.95	0.92	2.33	2.34	0.14
DJI	0	5.58	0.68	0.13	0.71	0.04
DMA	2	6.38	3.74	1.02	1.22	0.17
DNK	1	12.87	1.29	4.07	2.22	0.08
DOM	1	3.73	2.21	1.25	0.55	0.17
DZA	1	2.90	0.57	0.98	1.23	0.14
ECU	3	6.77	1.85	1.10	1.05	0.07
EGY	0	2.73	0.97	0.74	0.43	0.24
ERI	0	2.46	0.09	0.18	0.42	0.31
ESP	2	12.72	1.55	2.81	1.70	0.32
EST	1	8.09	1.46	2.53	2.37	0.08
ETH	1	1.62	0.06	0.17	0.21	0.38
FIN	2	15.54	1.18	1.59	2.89	0.06
FJI	1	10.47	2.26	1.21	0.49	0.19
FRA	1	12.72	1.61	2.74	2.63	0.11
FSM	1	12.60	3.31	1.70	0.92	0.03
GAB	1	4.15	1.76	0.31	0.49	0.21
GBR	2	12.58	1.97	1.96	2.35	0.15
GEO	2	6.13	0.68	1.35	1.97	0.04
GHA	1	1.36	0.54	0.26	0.16	0.21
GIN	0	2.03	0.13	0.54	0.19	0.25
GMB	1	1.66	0.66	0.50	0.36	0.18
GNB	0	6.24	0.18	0.19	0.26	0.07
GNQ	0	0.38	0.07	0.41	-	-
GRC	2	10.42	1.12	1.85	2.69	0.27
GRD	2	6.38	3.74	1.02	1.22	0.16
GTM	1	2.21	1.42	3.20	0.56	0.25

GUY	1	1.96	2.35	0.53	0.88	0.13
HND	2	2.67	2.10	1.10	1.12	0.21
HRV	1	7.65	0.66	2.14	1.94	0.11
HTI	0	2.98	0.34	0.13	0.25	0.24
HUN	1	9.09	2.84	3.35	1.68	0.11
IDN	1	0.79	0.68	1.58	0.11	0.18
IND	0	0.36	0.27	0.66	0.82	0.25
IRL	2	12.39	1.86	1.37	2.78	0.10
IRN	2	3.41	1.33	1.90	0.73	0.23
IRQ	0	0.61	0.22	0.40	0.39	0.10
ISL	2	14.90	1.39	1.55	3.39	0.03
ISR	2	4.51	4.64	1.86	1.64	0.28
ITA	0	12.17	0.96	2.22	2.43	0.23
JAM	1	3.44	4.65	0.71	1.12	0.10
JOR	2	3.99	2.20	1.41	1.12	0.24
JPN	1	5.25	1.10	4.01	0.83	0.29
KAZ	1	6.64	0.93	1.33	2.39	0.02
KEN	0	3.58	0.10	0.46	0.88	0.32
KGZ	0	8.15	0.27	0.74	2.32	0.08
KHM	0	4.83	0.32	0.62	0.07	0.13
KIR	1	12.60	3.31	1.70	0.92	0.03
KNA	2	6.38	3.74	1.02	1.22	0.17
KOR	1	9.04	1.11	2.65	0.25	0.21
KWT	1	6.40	4.40	2.77	1.58	0.32
LAO	0	4.48	0.52	0.91	0.07	0.12
LBN	3	6.32	1.93	1.67	1.18	0.42
LBR	0	2.23	0.70	0.62	0.08	0.12
LBY	2	3.14	1.20	2.48	1.13	0.19
LCA	2	6.38	3.74	1.02	1.22	0.18
LIE	1	14.68	0.85	1.93	2.61	0.12
LKA	0	0.64	0.53	0.77	0.49	0.23
LSO	0	4.03	0.38	0.18	0.24	0.13
LTU	1	8.09	1.46	2.53	2.37	0.08
LUX	1	8.77	1.41	2.42	2.41	0.09
LVA	1	8.09	1.46	2.53	2.37	0.08
MAR	2	2.89	1.03	1.49	0.40	0.20
MCO	1	12.72	1.61	2.74	2.63	0.10

MDA	3	3.75	1.33	2.00	1.75	0.04
MDG	0	4.08	0.66	0.24	0.40	0.11
MDV	3	1.69	1.71	1.50	0.73	0.20
MEX	1	7.28	2.09	3.41	1.07	0.31
MHL	1	12.60	3.31	1.70	0.92	0.03
MKD	3	1.76	0.53	1.05	1.41	0.16
MLI	0	3.59	0.34	0.12	0.77	0.23
MLT	0	12.17	0.96	2.22	2.43	0.22
MMR	2	4.76	1.37	1.24	0.26	0.36
MNE	2	5.01	0.53	1.05	1.41	0.16
MNG	1	21.96	0.05	0.29	1.11	0.03
MOZ	0	6.13	0.15	0.16	0.06	0.15
MRT	1	5.43	0.25	0.55	1.46	0.24
MUS	2	2.44	1.71	1.50	0.73	0.18
MWI	0	2.26	0.11	0.36	0.09	0.38
MYS	1	1.57	2.79	3.05	0.69	0.11
NAM	0	5.29	0.92	0.36	0.77	0.14
NER	0	7.19	0.14	0.12	0.89	0.54
NGA	1	1.35	0.15	0.93	0.16	0.36
NIC	2	1.77	1.59	0.85	0.85	0.40
NLD	1	9.52	1.28	3.47	3.04	0.17
NOR	0	11.97	0.75	2.00	2.28	0.09
NPL	0	0.81	0.08	0.40	0.72	0.24
NRU	1	12.60	3.31	1.70	0.92	0.03
NZL	0	13.15	2.71	2.07	0.89	0.19
OMN	1	6.40	4.40	2.77	1.58	0.29
PAK	1	2.62	0.26	0.59	1.85	0.13
PAN	1	4.38	2.19	1.25	0.96	0.13
PER	3	1.67	1.02	1.08	0.56	0.15
PHL	1	8.69	0.68	1.31	0.17	0.08
PLW	1	12.60	3.31	1.70	0.92	0.03
PNG	0	10.32	0.18	0.47	0.00	0.04
POL	2	10.82	1.40	2.40	1.59	0.07
PRK	1	2.50	0.13	1.10	0.05	0.28
PRT	3	10.80	1.52	1.79	1.99	0.16
PRY	0	8.49	0.66	3.80	0.75	0.29
QAT	1	6.40	4.40	2.77	1.58	0.33

ROU	1	7.35	1.45	3.02	2.98	0.08
RUS	2	6.59	1.22	2.96	1.74	0.06
RWA	1	1.74	0.03	0.09	0.26	0.67
SAU	0	2.69	2.43	0.96	0.92	0.13
SDN	1	6.93	0.11	0.34	2.00	0.27
SEN	0	2.39	0.35	0.54	0.51	0.16
SGP	0	7.64	2.56	2.95	0.98	-
SLB	0	4.68	0.12	0.39	0.09	0.15
SLE	0	0.51	0.29	0.39	0.11	0.41
SLV	3	1.87	1.24	2.03	1.14	0.31
SMR	0	12.17	0.96	2.22	2.43	0.19
SOM	0	9.92	0.11	0.11	3.92	0.07
SRB	2	5.01	0.53	1.05	1.41	0.16
SSD	1	6.93	0.11	0.34	2.00	0.27
STP	3	13.81	1.99	1.42	1.03	0.14
SUR	1	1.96	2.35	0.53	0.88	0.15
SVK	2	7.43	1.40	2.61	1.07	0.09
SVN	2	10.87	1.40	1.28	2.22	0.13
SWE	0	10.11	0.92	2.18	3.17	0.10
SWZ	1	8.15	0.92	1.45	0.90	0.25
SYC	2	2.44	1.71	1.50	0.73	0.19
SYR	1	5.37	0.83	2.31	1.63	0.39
TCD	0	3.10	0.09	0.10	0.32	0.72
TGO	0	2.36	0.59	0.25	0.14	0.26
THA	1	7.13	1.22	3.13	0.26	0.14
TJK	0	3.05	0.10	0.25	0.78	0.03
TKM	2	12.72	0.30	1.61	1.79	0.01
TLS	0	5.50	0.59	0.27	0.07	0.22
TON	1	12.60	3.31	1.70	0.92	0.03
TTO	2	6.38	3.74	1.02	1.22	0.18
TUN	1	3.86	0.99	1.65	0.98	0.28
TUR	2	2.26	1.02	2.28	1.34	0.36
TUV	1	12.60	3.31	1.70	0.92	0.03
TZA	0	2.60	0.20	0.26	0.47	0.52
UGA	0	3.96	0.20	0.17	0.50	0.46
UKR	2	5.07	1.18	2.96	1.86	0.09
URY	2	9.95	1.02	2.14	1.40	0.07

USA	0	10.37	3.11	2.85	2.51	0.26
UZB	1	5.77	0.12	0.88	1.61	0.02
VCT	2	6.38	3.74	1.02	1.22	0.16
VEN	2	3.56	1.83	1.01	0.73	0.09
VNM	0	12.96	0.60	0.83	0.15	0.23
VUT	0	13.34	0.83	0.66	0.25	0.16
WSM	1	12.60	3.31	1.70	0.92	0.03
YEM	0	2.11	0.77	0.47	0.44	0.11
ZAF	1	7.70	2.15	1.21	0.75	0.09
ZMB	0	2.44	0.45	0.92	0.15	0.13
ZWE	0	6.75	0.63	0.41	0.40	0.29

Appendix E: Protein Score Results, by Country (SSP3)

Country	Score	Red Meat	Poultry	Eggs	Dairy	Plant
AFG	0	2.66	0.13	0.18	0.85	0.03
AGO	1	1.99	0.32	0.18	0.13	0.12
ALB	1	3.95	0.81	1.19	3.47	0.15
AND	2	13.01	1.56	2.94	1.69	0.27
ARE	1	6.51	4.50	2.77	1.61	0.34
ARG	2	13.90	2.01	1.74	1.60	0.03
ARM	2	5.20	0.44	1.79	1.75	0.01
ATG	1	5.50	3.26	0.92	1.24	0.16
AUS	1	12.25	2.75	1.10	2.06	0.13
AUT	2	14.73	1.12	2.63	1.95	0.15
AZE	1	3.09	0.27	1.04	0.96	0.04
BDI	1	1.29	0.10	0.08	0.08	0.65
BEL	1	8.99	1.43	2.53	2.44	0.15
BEN	1	1.16	0.64	0.21	0.18	0.42
BFA	0	3.00	0.20	0.58	0.24	0.51
BGD	0	0.63	0.11	0.47	0.25	0.12
BGR	2	5.27	1.61	2.56	1.63	0.07
BHR	1	6.51	4.50	2.77	1.61	0.34
BHS	1	5.50	3.26	0.92	1.24	0.17
BIH	2	4.93	0.51	1.05	1.41	0.16
BLR	1	9.56	0.94	2.99	1.49	0.05
BLZ	0	3.81	2.40	0.75	1.00	0.27
BOL	2	6.85	1.57	1.01	0.35	0.17
BRA	2	8.37	2.37	1.44	1.52	0.28
BRB	1	5.50	3.26	0.92	1.24	0.18
BRN	2	1.46	2.59	2.97	1.00	-
BTN	0	2.24	0.05	0.14	0.50	0.24
BWA	1	2.95	0.25	0.45	1.03	0.17
CAF	0	7.32	0.14	0.08	0.26	0.12
CAN	1	8.46	2.87	2.20	1.82	0.26
CHE	0	15.07	0.85	2.01	2.65	0.16
CHL	1	9.60	2.38	1.27	0.94	0.11
CHN	0	14.22	0.94	3.96	0.54	0.26
CIV	1	1.07	0.17	0.41	0.19	0.18

CMR	0	2.18	0.25	0.14	0.22	0.39
COD	0	2.11	0.05	0.08	0.39	0.67
COG	1	1.19	0.72	0.16	0.25	0.12
COL	3	4.52	1.16	1.90	1.35	0.14
COM	3	1.45	1.32	1.24	0.73	0.16
CPV	3	10.44	1.54	1.18	1.04	0.14
CRI	3	3.45	1.41	1.88	1.78	0.27
CUB	2	4.39	1.04	1.50	0.74	0.44
CYP	3	9.07	1.69	1.79	1.77	0.17
CZE	2	9.93	2.01	1.86	1.91	0.12
DEU	0	11.26	0.93	2.43	2.33	0.14
DJI	0	4.69	0.58	0.12	0.72	0.04
DMA	1	5.50	3.26	0.92	1.24	0.16
DNK	1	13.24	1.31	4.24	2.24	0.08
DOM	1	3.48	2.04	1.21	0.55	0.16
DZA	1	2.49	0.52	0.91	1.27	0.13
ECU	3	6.08	1.59	1.05	1.04	0.07
EGY	0	2.37	0.85	0.66	0.44	0.22
ERI	1	1.68	0.05	0.13	0.39	0.27
ESP	2	13.01	1.56	2.94	1.69	0.31
EST	1	8.06	1.40	2.49	2.39	0.08
ETH	1	1.50	0.05	0.13	0.20	0.32
FIN	2	16.01	1.19	1.66	2.92	0.06
FJI	2	8.66	1.75	1.01	0.49	0.18
FRA	1	13.07	1.63	2.85	2.63	0.11
FSM	1	10.23	2.65	1.45	0.93	0.03
GAB	1	3.47	1.55	0.27	0.48	0.20
GBR	1	12.90	1.99	2.05	2.35	0.15
GEO	2	5.54	0.57	1.33	1.94	0.04
GHA	0	0.98	0.36	0.21	0.12	0.19
GIN	1	1.56	0.09	0.43	0.18	0.23
GMB	1	1.23	0.47	0.43	0.34	0.17
GNB	0	4.91	0.14	0.16	0.23	0.07
GNQ	0	0.37	0.07	0.37	-	-
GRC	2	10.34	1.09	1.86	2.70	0.27
GRD	1	5.50	3.26	0.92	1.24	0.15
GTM	2	1.91	1.17	2.97	0.55	0.22

GUY	1	1.86	2.33	0.52	0.88	0.13
HND	3	2.40	1.85	1.05	1.12	0.19
HRV	1	7.60	0.63	2.14	1.95	0.11
HTI	0	2.62	0.29	0.12	0.25	0.22
HUN	1	9.16	2.81	3.37	1.69	0.11
IDN	1	0.68	0.53	1.33	0.10	0.18
IND	0	0.30	0.16	0.53	0.75	0.23
IRL	2	12.71	1.88	1.42	2.77	0.10
IRN	2	3.27	1.29	1.84	0.72	0.22
IRQ	0	0.64	0.23	0.41	0.40	0.10
ISL	2	15.23	1.38	1.61	3.44	0.03
ISR	2	4.61	4.70	1.88	1.65	0.28
ITA	0	12.43	0.95	2.32	2.41	0.23
JAM	1	2.84	3.68	0.60	1.13	0.09
JOR	2	3.56	2.03	1.33	1.09	0.23
JPN	1	5.14	1.07	4.13	0.82	0.28
KAZ	1	6.72	0.93	1.33	2.43	0.02
KEN	0	3.11	0.06	0.37	0.91	0.29
KGZ	0	7.51	0.25	0.72	2.30	0.08
KHM	0	4.45	0.25	0.48	0.07	0.12
KIR	1	10.23	2.65	1.45	0.93	0.03
KNA	1	5.50	3.26	0.92	1.24	0.16
KOR	1	8.54	1.08	2.67	0.25	0.20
KWT	1	6.51	4.50	2.77	1.61	0.32
LAO	0	4.08	0.42	0.71	0.06	0.11
LBN	3	5.62	1.79	1.58	1.15	0.41
LBR	1	1.51	0.48	0.51	0.06	0.11
LBY	2	3.01	1.16	2.41	1.13	0.19
LCA	1	5.50	3.26	0.92	1.24	0.17
LIE	0	15.07	0.85	2.01	2.65	0.12
LKA	0	0.48	0.42	0.64	0.45	0.21
LSO	0	3.33	0.31	0.15	0.22	0.12
LTU	1	8.06	1.40	2.49	2.39	0.08
LUX	1	8.99	1.43	2.53	2.44	0.09
LVA	1	8.06	1.40	2.49	2.39	0.08
MAR	1	2.45	0.91	1.37	0.38	0.18
MCO	1	13.07	1.63	2.85	2.63	0.10

MDA	3	3.61	1.19	1.99	1.75	0.04
MDG	0	3.18	0.50	0.21	0.37	0.10
MDV	3	1.45	1.32	1.24	0.73	0.19
MEX	2	6.96	1.97	3.37	1.09	0.29
MHL	1	10.23	2.65	1.45	0.93	0.03
MKD	3	1.73	0.51	1.05	1.41	0.16
MLI	0	2.99	0.25	0.10	0.74	0.21
MLT	0	12.43	0.95	2.32	2.41	0.22
MMR	1	3.71	1.10	0.99	0.25	0.34
MNE	2	4.93	0.51	1.05	1.41	0.16
MNG	1	18.86	0.04	0.24	1.23	0.02
MOZ	0	4.04	0.13	0.14	0.06	0.14
MRT	1	4.62	0.20	0.46	1.60	0.22
MUS	3	2.00	1.32	1.24	0.73	0.17
MWI	1	1.74	0.09	0.31	0.07	0.35
MYS	1	1.32	2.61	2.92	0.68	0.10
NAM	0	4.58	0.81	0.33	0.76	0.13
NER	0	4.82	0.08	0.09	0.72	0.49
NGA	1	1.08	0.12	0.77	0.12	0.34
NIC	2	1.58	1.40	0.80	0.85	0.37
NLD	1	9.73	1.27	3.62	3.09	0.17
NOR	0	12.35	0.76	2.08	2.30	0.09
NPL	0	0.59	0.05	0.30	0.63	0.21
NRU	1	10.23	2.65	1.45	0.93	0.03
NZL	0	13.08	2.70	2.09	0.89	0.19
OMN	1	6.51	4.50	2.77	1.61	0.29
PAK	1	2.14	0.21	0.52	1.84	0.12
PAN	1	4.19	2.10	1.22	0.97	0.12
PER	2	1.56	0.94	1.05	0.56	0.14
PHL	1	7.59	0.59	1.14	0.15	0.08
PLW	1	10.23	2.65	1.45	0.93	0.03
PNG	0	8.51	0.14	0.40	0.00	0.04
POL	2	10.94	1.40	2.42	1.59	0.07
PRK	1	2.51	0.13	1.15	0.06	0.28
PRT	3	11.01	1.51	1.87	1.97	0.16
PRY	0	8.16	0.60	3.66	0.75	0.27
QAT	1	6.51	4.50	2.77	1.61	0.32

ROU	1	7.15	1.33	3.02	2.98	0.08
RUS	2	6.62	1.20	2.93	1.75	0.06
RWA	1	1.24	0.02	0.07	0.23	0.59
SAU	0	2.76	2.53	0.97	0.95	0.13
SDN	0	5.28	0.09	0.30	2.15	0.25
SEN	1	1.82	0.26	0.43	0.42	0.15
SGP	1	7.54	2.59	2.97	1.00	-
SLB	0	3.48	0.09	0.31	0.09	0.14
SLE	0	0.41	0.22	0.33	0.08	0.38
SLV	4	1.72	1.14	1.96	1.14	0.29
SMR	0	12.43	0.95	2.32	2.41	0.18
SOM	0	5.42	0.06	0.08	2.89	0.06
SRB	2	4.93	0.51	1.05	1.41	0.16
SSD	0	5.28	0.09	0.30	2.15	0.25
STP	3	10.44	1.54	1.18	1.04	0.14
SUR	1	1.86	2.33	0.52	0.88	0.14
SVK	2	7.50	1.39	2.63	1.07	0.08
SVN	2	10.98	1.40	1.29	2.22	0.13
SWE	0	10.41	0.93	2.27	3.20	0.10
SWZ	1	6.57	0.64	1.25	0.87	0.23
SYC	3	2.00	1.32	1.24	0.73	0.18
SYR	1	4.71	0.75	2.15	1.58	0.37
TCD	0	2.54	0.06	0.08	0.31	0.68
TGO	1	1.68	0.41	0.21	0.11	0.24
THA	1	6.13	1.09	2.78	0.26	0.13
TJK	0	2.59	0.08	0.25	0.74	0.03
TKM	2	12.37	0.29	1.61	1.77	0.01
TLS	0	3.69	0.35	0.18	0.05	0.20
TON	1	10.23	2.65	1.45	0.93	0.03
TTO	1	5.50	3.26	0.92	1.24	0.17
TUN	2	3.54	0.94	1.59	1.01	0.27
TUR	1	2.04	0.89	2.15	1.37	0.34
TUV	1	10.23	2.65	1.45	0.93	0.03
TZA	0	2.19	0.15	0.22	0.43	0.48
UGA	0	3.20	0.15	0.14	0.45	0.42
UKR	2	4.99	1.08	2.89	1.88	0.09
URY	1	9.56	0.99	2.09	1.41	0.06

USA	0	10.61	3.20	2.89	2.53	0.26
UZB	1	5.57	0.10	0.85	1.60	0.02
VCT	1	5.50	3.26	0.92	1.24	0.16
VEN	2	3.68	1.97	1.03	0.74	0.09
VNM	0	12.05	0.53	0.73	0.14	0.22
VUT	0	10.12	0.64	0.55	0.25	0.16
WSM	1	10.23	2.65	1.45	0.93	0.03
YEM	1	1.80	0.70	0.43	0.42	0.11
ZAF	2	6.69	2.00	1.23	0.69	0.09
ZMB	1	1.94	0.33	0.78	0.12	0.12
ZWE	0	4.78	0.47	0.35	0.37	0.26

Appendix F: Protein Daily Cost Results, by Country (All Scenarios)

	Animal Protein Daily Cost, $2005			Plant Protein Daily Cost, $2005		
Country	**SSP1**	**SSP2**	**SSP3**	**SSP1**	**SSP2**	**SSP3**
AFG	0.50	0.46	0.39	0.04	0.05	0.05
AGO	0.53	0.49	0.42	0.04	0.05	0.04
ALB	0.49	0.45	0.38	0.04	0.05	0.04
AND	0.41	0.37	0.32	0.04	0.05	0.04
ARE	0.54	0.50	0.43	0.04	0.05	0.04
ARG	0.44	0.41	0.35	0.04	0.05	0.04
ARM	0.48	0.44	0.38	0.04	0.05	0.04
ATG	0.47	0.43	0.37	0.04	0.05	0.04
AUS	0.40	0.37	0.32	0.04	0.05	0.04
AUT	0.41	0.37	0.32	0.04	0.04	0.04
AZE	0.54	0.49	0.42	0.04	0.05	0.04
BDI	0.53	0.49	0.42	0.05	0.05	0.05
BEL	0.41	0.37	0.32	0.04	0.05	0.04
BEN	0.53	0.48	0.42	0.04	0.05	0.05
BFA	0.57	0.52	0.44	0.04	0.05	0.05
BGD	0.50	0.46	0.39	0.05	0.05	0.05
BGR	0.45	0.41	0.36	0.05	0.05	0.05
BHR	0.54	0.50	0.43	0.04	0.05	0.04
BHS	0.47	0.43	0.37	0.04	0.05	0.04
BIH	0.44	0.40	0.35	0.04	0.04	0.04
BLR	0.48	0.44	0.38	0.04	0.05	0.04
BLZ	0.44	0.41	0.35	0.04	0.05	0.04
BOL	0.46	0.42	0.36	0.04	0.05	0.04
BRA	0.45	0.41	0.35	0.04	0.05	0.04
BRB	0.47	0.43	0.37	0.04	0.05	0.04
BRN	0.48	0.44	0.38	0.04	0.05	0.04
BTN	0.47	0.43	0.37	0.04	0.05	0.05
BWA	0.51	0.46	0.40	0.04	0.04	0.04
CAF	0.55	0.50	0.43	0.05	0.05	0.05
CAN	0.43	0.40	0.34	0.04	0.05	0.04
CHE	0.44	0.41	0.35	0.06	0.06	0.06
CHL	0.44	0.40	0.35	0.04	0.04	0.04
CHN	0.46	0.42	0.36	0.04	0.05	0.04

CIV	0.53	0.48	0.42	0.04	0.05	0.05
CMR	0.55	0.50	0.43	0.05	0.05	0.05
COD	0.53	0.49	0.42	0.04	0.05	0.04
COG	0.53	0.49	0.42	0.04	0.05	0.04
COL	0.46	0.42	0.36	0.04	0.05	0.05
COM	0.47	0.43	0.37	0.04	0.04	0.04
CPV	0.44	0.40	0.35	0.04	0.04	0.04
CRI	0.44	0.41	0.35	0.04	0.05	0.04
CUB	0.47	0.43	0.37	0.04	0.05	0.04
CYP	0.47	0.43	0.38	0.04	0.04	0.04
CZE	0.44	0.40	0.35	0.04	0.04	0.04
DEU	0.41	0.37	0.32	0.04	0.05	0.04
DJI	0.57	0.52	0.45	0.05	0.05	0.05
DMA	0.47	0.43	0.37	0.04	0.05	0.04
DNK	0.41	0.37	0.32	0.04	0.05	0.04
DOM	0.47	0.43	0.37	0.04	0.05	0.04
DZA	0.54	0.49	0.42	0.05	0.05	0.05
ECU	0.45	0.41	0.36	0.04	0.05	0.05
EGY	0.51	0.47	0.41	0.04	0.05	0.04
ERI	0.51	0.47	0.40	0.05	0.05	0.05
ESP	0.41	0.37	0.32	0.04	0.05	0.04
EST	0.47	0.43	0.37	0.04	0.04	0.04
ETH	0.53	0.49	0.42	0.05	0.05	0.05
FIN	0.40	0.37	0.32	0.04	0.04	0.04
FJI	0.47	0.43	0.37	0.04	0.05	0.04
FRA	0.41	0.37	0.32	0.04	0.04	0.04
FSM	0.47	0.43	0.37	0.04	0.05	0.04
GAB	0.55	0.50	0.43	0.05	0.05	0.05
GBR	0.41	0.37	0.32	0.04	0.04	0.04
GEO	0.49	0.45	0.39	0.04	0.05	0.04
GHA	0.53	0.48	0.42	0.04	0.05	0.05
GIN	0.57	0.52	0.44	0.04	0.05	0.05
GMB	0.57	0.52	0.44	0.04	0.05	0.05
GNB	0.53	0.48	0.42	0.04	0.05	0.05
GNQ	0.55	0.50	0.43	0.05	0.05	0.05
GRC	0.44	0.41	0.35	0.04	0.05	0.04
GRD	0.47	0.43	0.37	0.04	0.05	0.04

GTM	0.44	0.41	0.35	0.04	0.05	0.04
GUY	0.48	0.44	0.38	0.05	0.05	0.05
HND	0.44	0.41	0.35	0.04	0.05	0.04
HRV	0.45	0.42	0.36	0.04	0.05	0.04
HTI	0.47	0.43	0.37	0.04	0.05	0.04
HUN	0.44	0.40	0.35	0.04	0.05	0.04
IDN	0.48	0.44	0.38	0.04	0.05	0.04
IND	0.45	0.42	0.36	0.07	0.07	0.07
IRL	0.41	0.37	0.32	0.04	0.04	0.04
IRN	0.56	0.51	0.44	0.04	0.05	0.04
IRQ	0.54	0.50	0.43	0.04	0.05	0.04
ISL	0.45	0.41	0.35	0.04	0.05	0.05
ISR	0.47	0.43	0.36	0.04	0.05	0.04
ITA	0.41	0.37	0.32	0.04	0.05	0.04
JAM	0.47	0.43	0.37	0.04	0.05	0.04
JOR	0.54	0.50	0.43	0.04	0.05	0.04
JPN	0.42	0.39	0.34	0.04	0.05	0.04
KAZ	0.51	0.47	0.40	0.04	0.05	0.04
KEN	0.53	0.49	0.42	0.05	0.05	0.05
KGZ	0.51	0.47	0.40	0.04	0.05	0.04
KHM	0.47	0.43	0.37	0.05	0.05	0.05
KIR	0.47	0.43	0.37	0.04	0.05	0.04
KNA	0.47	0.43	0.37	0.04	0.05	0.04
KOR	0.45	0.42	0.36	0.08	0.08	0.08
KWT	0.54	0.50	0.43	0.04	0.05	0.04
LAO	0.46	0.42	0.36	0.05	0.05	0.05
LBN	0.54	0.50	0.43	0.04	0.05	0.04
LBR	0.53	0.48	0.42	0.04	0.05	0.05
LBY	0.54	0.49	0.42	0.05	0.05	0.05
LCA	0.47	0.43	0.37	0.04	0.05	0.04
LIE	0.44	0.41	0.35	0.06	0.06	0.06
LKA	0.46	0.42	0.36	0.05	0.05	0.05
LSO	0.51	0.46	0.40	0.04	0.05	0.04
LTU	0.47	0.43	0.37	0.04	0.04	0.04
LUX	0.41	0.37	0.32	0.04	0.05	0.04
LVA	0.47	0.43	0.37	0.04	0.04	0.04
MAR	0.58	0.53	0.45	0.04	0.05	0.05

MCO	0.41	0.37	0.32	0.04	0.04	0.04
MDA	0.44	0.40	0.35	0.04	0.05	0.04
MDG	0.51	0.47	0.40	0.04	0.05	0.04
MDV	0.47	0.43	0.37	0.04	0.04	0.04
MEX	0.44	0.41	0.35	0.04	0.05	0.04
MHL	0.47	0.43	0.37	0.04	0.05	0.04
MKD	0.47	0.43	0.37	0.04	0.04	0.04
MLI	0.57	0.52	0.45	0.05	0.05	0.05
MLT	0.41	0.37	0.32	0.04	0.05	0.04
MMR	0.44	0.40	0.35	0.04	0.04	0.04
MNE	0.44	0.40	0.35	0.04	0.04	0.04
MNG	0.46	0.42	0.36	0.04	0.05	0.04
MOZ	0.52	0.48	0.41	0.04	0.05	0.05
MRT	0.57	0.52	0.44	0.04	0.05	0.05
MUS	0.44	0.40	0.35	0.04	0.04	0.04
MWI	0.51	0.47	0.40	0.04	0.05	0.04
MYS	0.47	0.43	0.37	0.04	0.05	0.04
NAM	0.51	0.46	0.40	0.04	0.05	0.04
NER	0.57	0.52	0.44	0.04	0.05	0.05
NGA	0.62	0.56	0.48	0.06	0.06	0.06
NIC	0.45	0.41	0.35	0.04	0.05	0.04
NLD	0.41	0.37	0.32	0.04	0.05	0.04
NOR	0.42	0.39	0.33	0.06	0.07	0.07
NPL	0.47	0.43	0.37	0.04	0.05	0.05
NRU	0.47	0.43	0.37	0.04	0.05	0.04
NZL	0.40	0.37	0.32	0.04	0.04	0.04
OMN	0.54	0.50	0.43	0.04	0.05	0.04
PAK	0.49	0.45	0.38	0.05	0.05	0.05
PAN	0.45	0.41	0.36	0.04	0.05	0.04
PER	0.46	0.42	0.36	0.04	0.05	0.04
PHL	0.46	0.42	0.37	0.04	0.05	0.04
PLW	0.47	0.43	0.37	0.04	0.05	0.04
PNG	0.47	0.43	0.37	0.04	0.05	0.04
POL	0.44	0.40	0.35	0.04	0.04	0.04
PRK	0.46	0.42	0.36	0.04	0.05	0.04
PRT	0.40	0.37	0.32	0.04	0.05	0.04
PRY	0.44	0.41	0.35	0.04	0.05	0.04

QAT	0.54	0.50	0.43	0.04	0.05	0.04
ROU	0.46	0.42	0.37	0.04	0.05	0.05
RUS	0.49	0.44	0.38	0.04	0.05	0.04
RWA	0.53	0.49	0.42	0.05	0.05	0.05
SAU	0.54	0.50	0.43	0.04	0.05	0.04
SDN	0.57	0.52	0.45	0.05	0.05	0.05
SEN	0.56	0.51	0.44	0.04	0.05	0.04
SGP	0.44	0.41	0.35	0.04	0.05	0.04
SLB	0.47	0.43	0.37	0.04	0.05	0.04
SLE	0.57	0.52	0.44	0.04	0.05	0.05
SLV	0.44	0.41	0.35	0.04	0.05	0.04
SMR	0.41	0.37	0.32	0.04	0.05	0.04
SOM	0.57	0.52	0.45	0.05	0.05	0.05
SRB	0.44	0.40	0.35	0.04	0.04	0.04
SSD	0.40	0.38	0.34	0.04	0.05	0.05
STP	0.44	0.40	0.35	0.04	0.04	0.04
SUR	0.48	0.44	0.38	0.05	0.05	0.05
SVK	0.44	0.40	0.35	0.04	0.04	0.04
SVN	0.44	0.40	0.35	0.04	0.04	0.04
SWE	0.41	0.37	0.32	0.04	0.04	0.04
SWZ	0.51	0.46	0.40	0.04	0.05	0.04
SYC	0.44	0.40	0.35	0.04	0.04	0.04
SYR	0.54	0.50	0.43	0.04	0.05	0.04
TCD	0.59	0.54	0.46	0.05	0.05	0.05
TGO	0.53	0.48	0.42	0.04	0.05	0.05
THA	0.45	0.41	0.36	0.05	0.06	0.05
TJK	0.53	0.48	0.41	0.04	0.05	0.04
TKM	0.53	0.48	0.41	0.04	0.05	0.04
TLS	0.44	0.41	0.35	0.04	0.05	0.04
TON	0.47	0.43	0.37	0.04	0.05	0.04
TTO	0.47	0.43	0.37	0.04	0.05	0.04
TUN	0.67	0.60	0.52	0.05	0.05	0.05
TUR	0.52	0.48	0.41	0.04	0.05	0.05
TUV	0.47	0.43	0.37	0.04	0.05	0.04
TZA	0.54	0.49	0.42	0.05	0.05	0.05
UGA	0.52	0.48	0.41	0.04	0.05	0.04
UKR	0.48	0.44	0.38	0.05	0.06	0.05

URY	0.44	0.41	0.35	0.04	0.04	0.04
USA	0.40	0.37	0.32	0.04	0.05	0.04
UZB	0.53	0.48	0.41	0.04	0.05	0.04
VCT	0.47	0.43	0.37	0.04	0.05	0.04
VEN	0.46	0.42	0.36	0.04	0.05	0.05
VNM	0.45	0.41	0.35	0.04	0.05	0.04
VUT	0.47	0.43	0.37	0.04	0.05	0.04
WSM	0.47	0.43	0.37	0.04	0.05	0.04
YEM	0.54	0.50	0.43	0.04	0.05	0.04
ZAF	0.41	0.37	0.32	0.04	0.05	0.04
ZMB	0.53	0.48	0.42	0.04	0.05	0.04
ZWE	0.53	0.49	0.42	0.04	0.05	0.05