Four Legs, Two Legs, No Legs: What Does Science Tell Us About the Best Sources of Sustainable Protein?

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What is the "best" source of sustainable protein? There is no easy answer to that question. It all depends upon what sustainable means to you, and which metric(s) of sustainability you want to guide your decisions. Definitions of sustainability generally have to do with living within the limits of, and understanding the interconnections among, the three pillars of sustainability: economic, environmental and social. People put varying emphasis on these different pillars. Consider this graphic below (**Figure 1**) – which is the sustainable system? There is no one correct answer since it will depend upon the weighting you put on the various competing pillars of sustainability. There are pros and cons to each of the various scenarios.

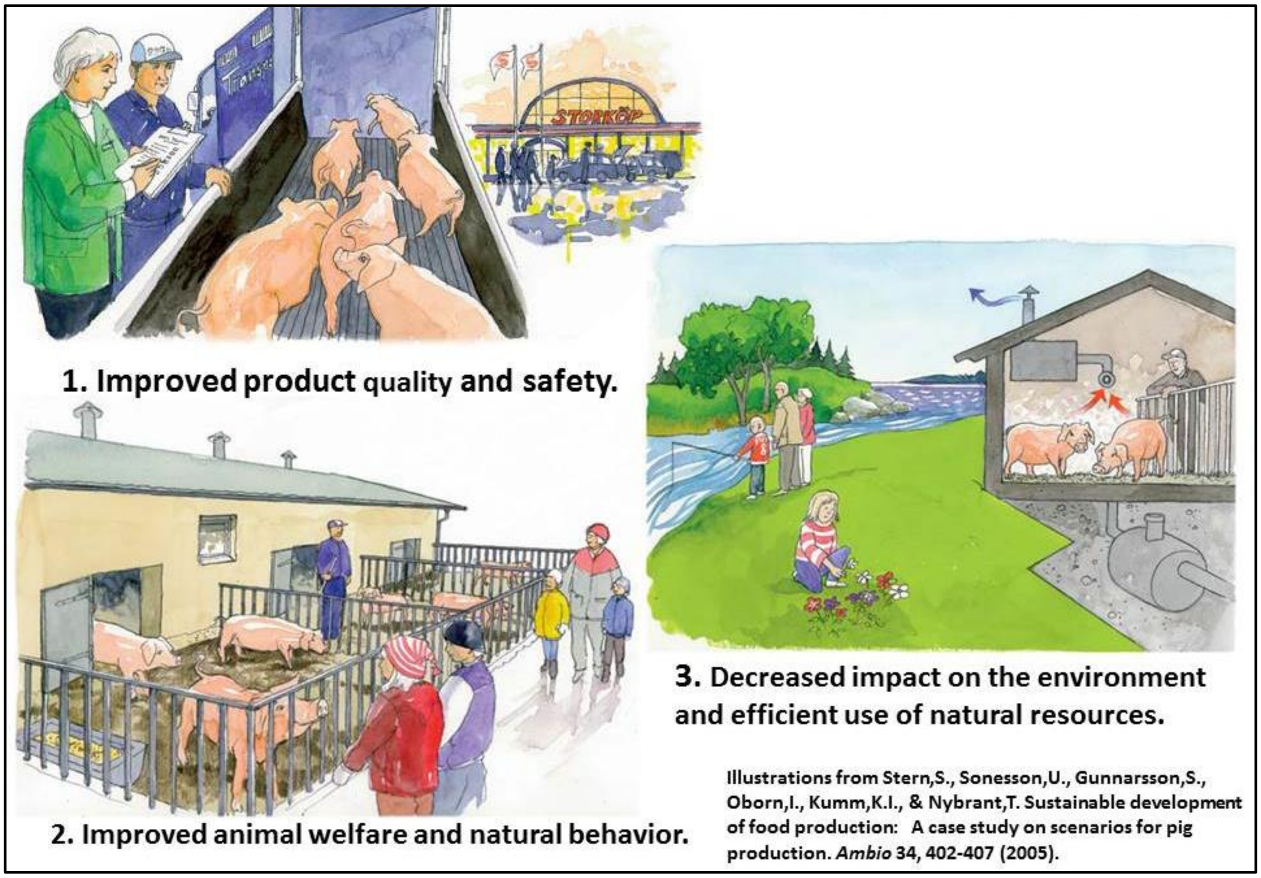


Figure 1. Which system is sustainable? (8).

These tradeoffs occur more generally in all of our food chocies. For example, some people swear by grass fed beef – but based on a carbon footprint per unit of protein perspective, it is much less efficient and therefore has a bigger carbon footprint per kg beef than intensively raised beef (7). Others advocate obtaining protein from nuts, but from a water footprint per unit of protein perspective they are more water intensive than all animal products (6). Others swear by wild-caught fish, but from a carbon footprint perspective, animal products from this source are very energy intensive if they involve bottom trawling and longline fishing (10). And let's not even get into the issue of air miles which can make even the innocuous asparagus appear to be public enemy number one (5) based on CO_2-equvalents per unit weight of food product (**Figure 2**).

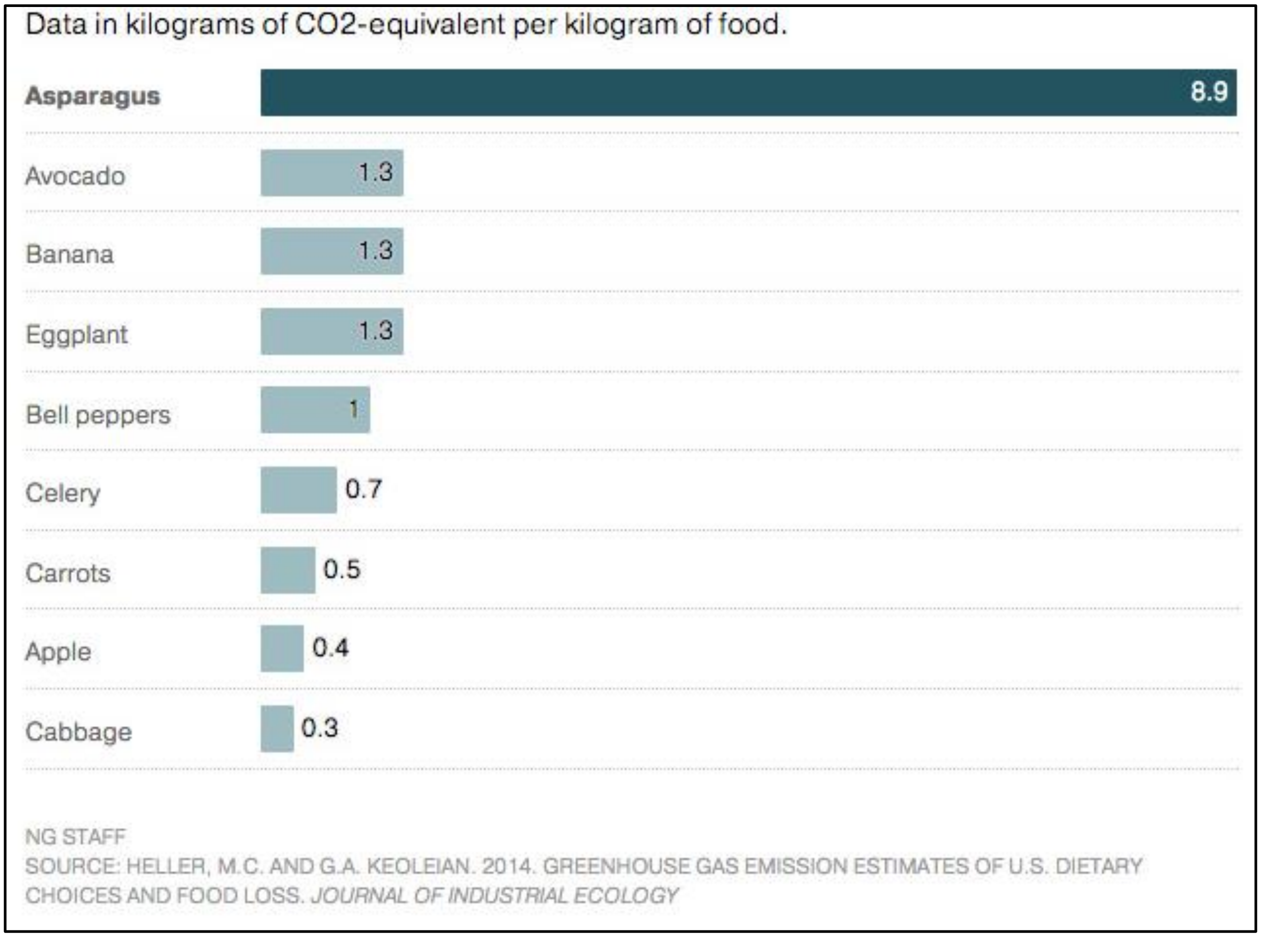


Figure 2. Carbon emissions (CO_2-equivalent/kg) for fruits and vegetables on a weight basis (5). Source: http://theplate.nationalgeographic.com/files/2016/02/carbonemissions.jpg

The sustainability question becomes even more complicated when considering the requirements for a nutritionally-balanced diet. Although it may seem like switching to a diet with less red meat and more fruits, fish and milk should be desirable from an environmental perspective, it may actually exacerbate climate change due to the relatively high energy and water use per calorie of these food products. A recent research paper (10) compared 3 different scenarios: 1) a reduced calorie diet (-300 calories/day) with the same mix of food as the average US diet; 2) the USDA-recommended food mix without reducing the total calories of an average diet; 3) reducing calories AND shifting to the USDA-recommended food mix. The first option resulted in a desirable 10% reduction in energy use, water use and emissions. The second scenario increased energy use (43%), water use (16%), and emissions (11%). Even when reducing calories on the USDA-recommended diet, the scenario 3 diet resulted in a significant increase in energy (38%), water use (10%), and emissions (6%) compared with the current status quo.

Why are the "costs" of these scenarios so different? Because fruit, fish, and dairy – as emphasized in the USDA guidelines – are foods that on a per calorie basis require the most energy and water to grow (**Figure 3**).

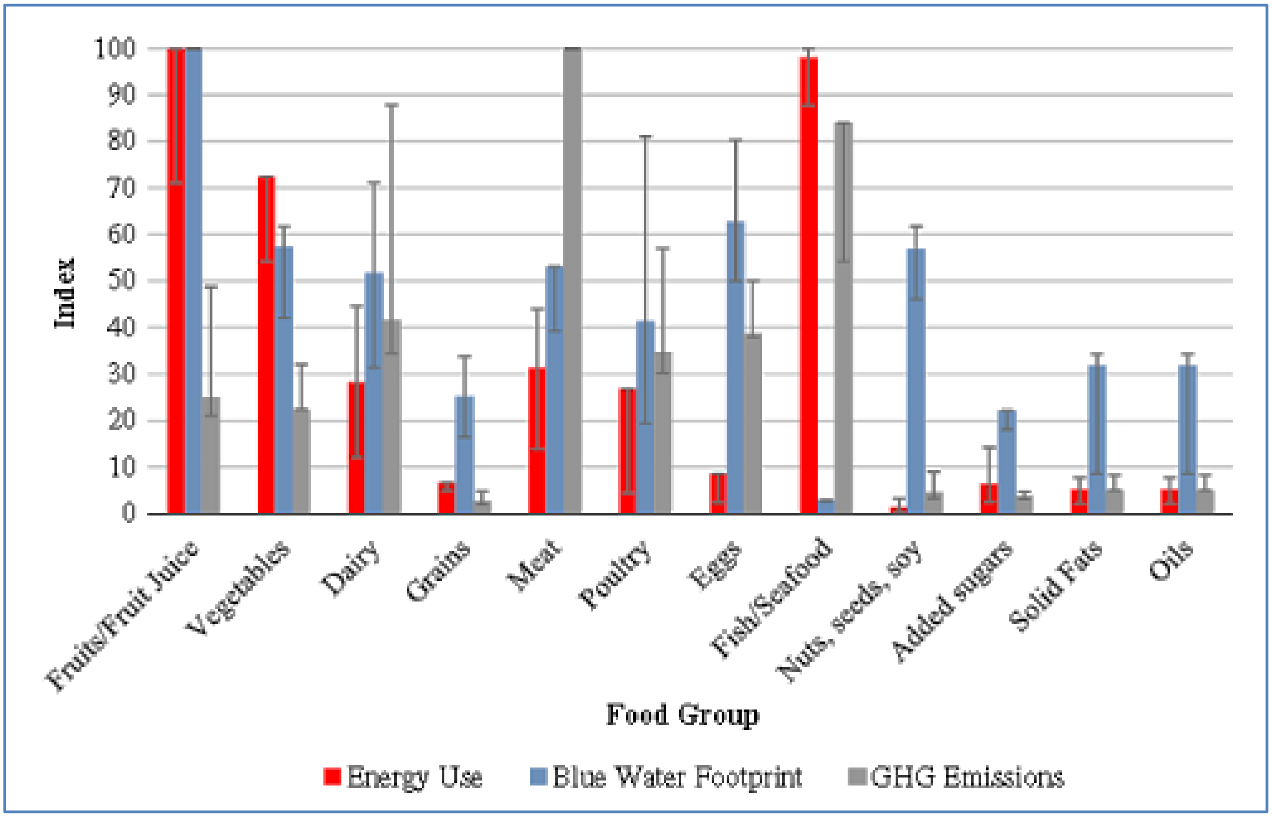


Figure 3. Input/emissions per calorie from some common US dietary items on calorie basis (10).

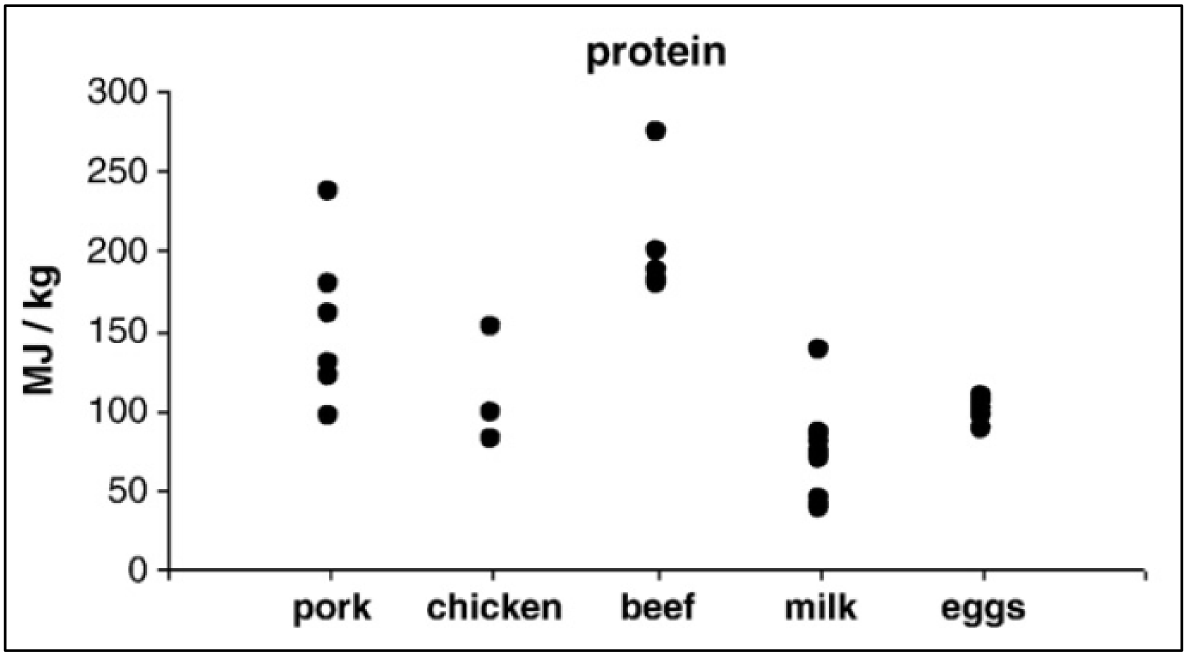
http://www.nature.com/scitable/blog/eyes-on-environment/beyond_the_headlines_clarifying_the

In contrast, added sugars, fats, oils, and grains require fewer resources and create fewer emissions per calorie. So although these might be the most environmentally-friendly sources of calories, they are not likely to be the ones that are recommended for consumption in large quantities as part of a healthy diet. If you totally forget health and consume a diet that would have the least impact on the environment, you would eat a lot more fats and sugars. Additionally, grains are also an excellent source of calories despite the fact they tend to be vilified in US dietary culture.

The bottom line is that food is more than calories and protein, and the dietary mix of foods and their availability will determine the best balance for a healthy diet. Adding in sustainability metrics complicates the discussion, and often conflicting results will be generated depending upon which metric is being optimized. Sometimes the most environmentally friendly diet might be the least healthy option. As with all discussions around sustainability, and agricultural production systems in general (organic, conventional, genetically engineered etc.), it is complicated and there are tradeoffs. Beware of anyone who touts a seemingly magic solution. There will never be black and white answers to the questions of which foods are the most sustainable, other than perhaps just eating less of whatever you are currently eating. Although this is a privileged first-world perspective, as evidenced by the approximately 25,000 people who die of malnutrition or starvation daily. As the saying goes, "A well-fed man (perhaps we could substitute society in here) has many problems (and food choices!), a starving man has but one."

So back to the original question posed in this paper, **"What Does Science Tell Us About the Best Sources of Sustainable Protein?"** If we are talking about animal sources of protein, the answer, again, is that it depends. Some things are biological facts that do not change irrespective of other factors. One is that the feed conversion efficiency (i.e. how many units of feed are required to produce a unit of animal product) of monogastrics (single stomach animals - fish, pigs, and chickens) is better (i.e. less) than ruminant animals (cows, sheep, goats) (**Figure 4**).

Figure 4. Energy use to produce various livestock products, in MJ per kg protein (3).



That may seem to indicate to eat only meat from monogastrics – but that is not always the case. Milk, for example, has a relatively good conversion ratio, but what about the CO_2-equivalent per unit weight of product? See **Figure 5**. Here beef fares poorly versus milk and eggs.

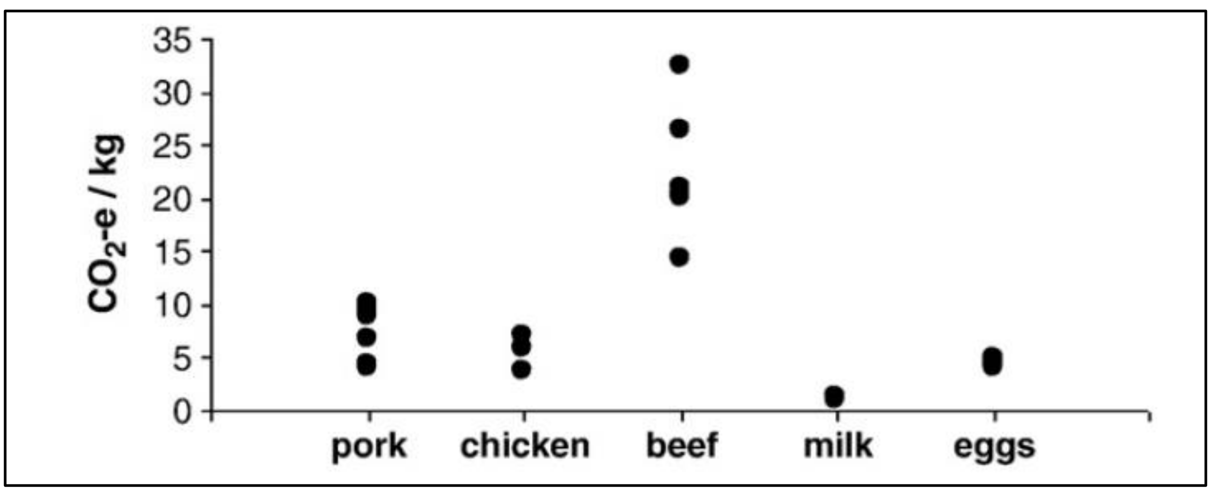


Figure 5 Global warming potential for livestock products, in CO_2-equivalents per kg product (3).

But a kg of milk contains less protein than a kg of beef, so **Figure 6** is based on kg protein.

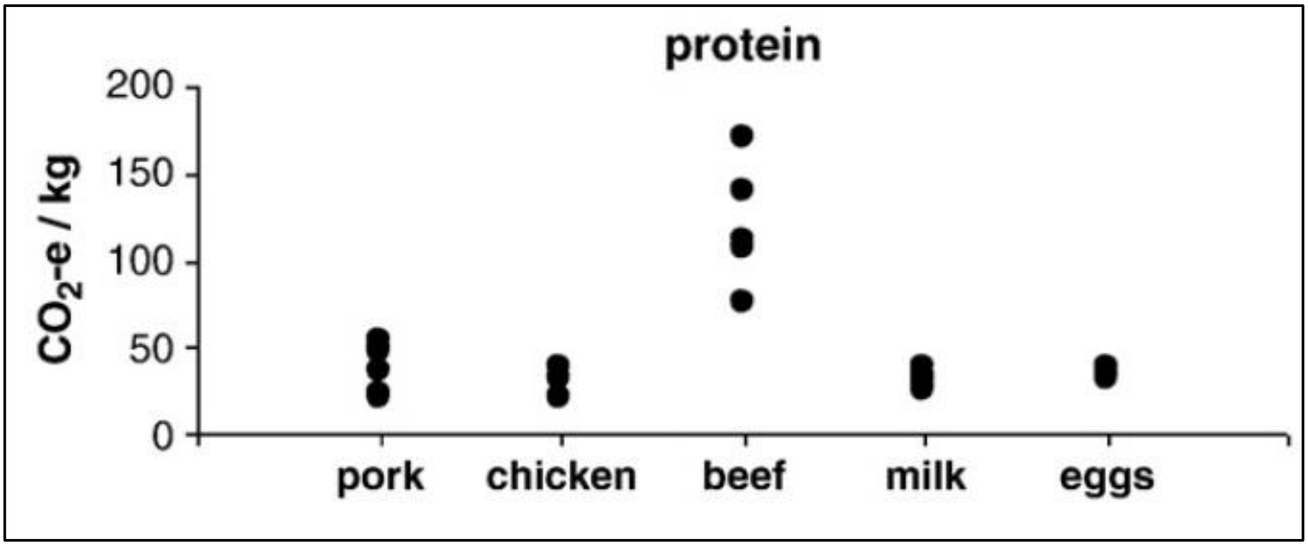


Figure 6. Global warming potential for livestock products, in CO_2-equivalents per kg protein (3).

Figure 7 is also on a kg protein basis, and includes sheep, different forms of beef production, and seafood in comparison to vegetal sources of protein, and meat substitutes, some of which can have a higher carbon footprint than the meat for which they are substituting.

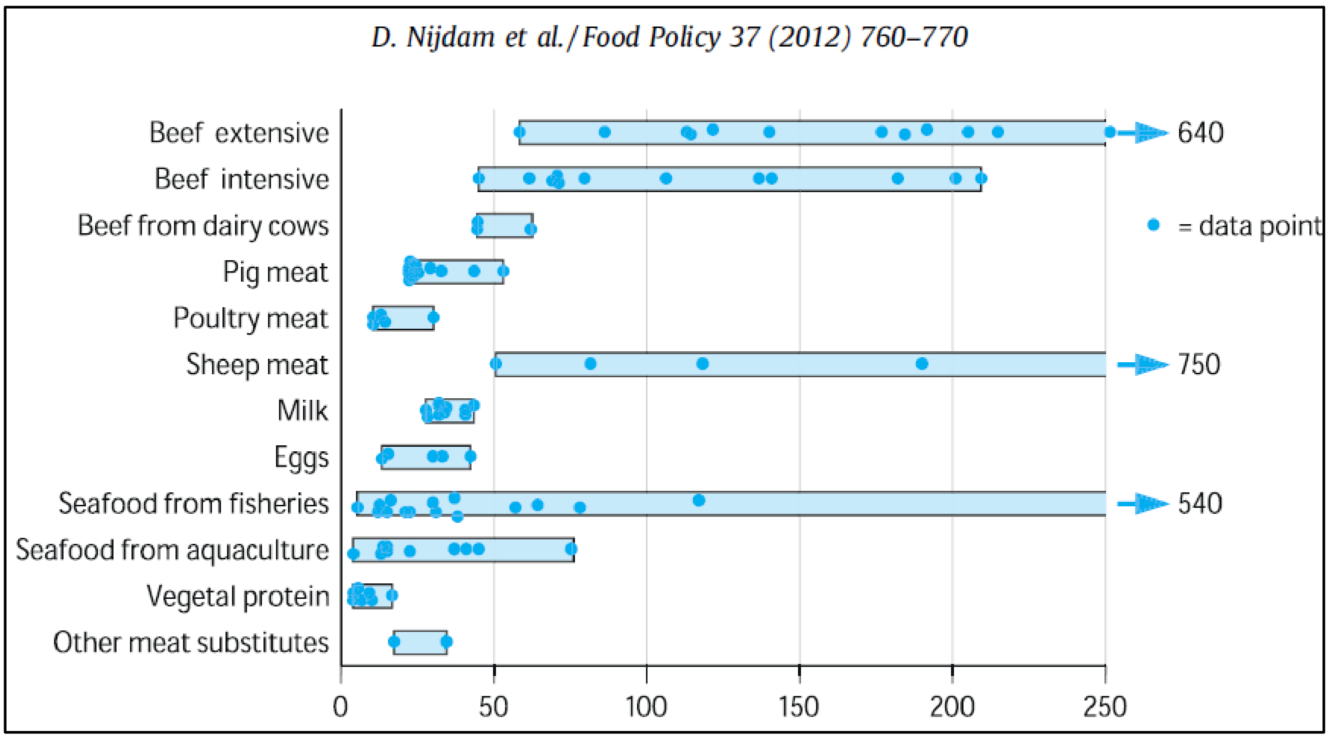


Figure 7. Global warming potential for food products, in CO_2-equivalents per kg protein (7).

So is that the end of the story? No; not even close. What about the water footprint of our protein sources? **Figure 8** shows fruits and nuts are worse than beef on a volume of water per unit of protein basis. On a volume of water per unit of fat basis, fruits, starchy roots, vegetables and pulses are the most inefficient. And butter is the most sustainable (least water/g fat) source of fat!

Food item	Water footprint per ton (m^3/ton)				Nutritional content			Water footprint per unit of nutritional value		
	Green	Blue	Grey	Total	Calorie (kcal/kg)	Protein (g/kg)	Fat (g/kg)	Calorie (liter/kcal)	Protein (liter/g protein)	Fat (liter/g fat)
Sugar crops	130	52	15	197	285	0.0	0.0	0.69	0.0	0.0
Vegetables	194	43	85	322	240	12	2.1	1.34	26	154
Starchy roots	327	16	43	387	827	13	1.7	0.47	31	226
Fruits	726	147	89	962	460	5.3	2.8	2.09	180	348
Cereals	1,232	228	184	1,644	3,208	80	15	0.51	21	112
Oil crops	2,023	220	121	2,364	2,908	146	209	0.81	16	11
Pulses	3,180	141	734	4,055	3,412	215	23	1.19	19	180
Nuts	7,016	1367	680	9,063	2,500	65	193	3.63	139	47
Milk	863	86	72	1,020	560	33	31	1.82	31	33
Eggs	2,592	244	429	3,265	1,425	111	100	2.29	29	33
Chicken meat	3,545	313	467	4,325	1,440	127	100	3.00	34	43
Butter	4,695	465	393	5,553	7,692	0.0	872	0.72	0.0	6.4
Pig meat	4,907	459	622	5,988	2,786	105	259	2.15	57	23
Sheep/goat meat	8,253	457	53	8,763	2,059	139	163	4.25	63	54
Beef	14,414	550	451	15,415	1,513	138	101	10.19	112	153

Figure 8. The water footprint of some selected food products from vegetable and animal origin (6).

What about land use per kg of protein? **Figure 9** shows this on a per kg protein basis. Extensive beef production looks really bad here. But what are cattle grazing on? Typically non-human edible feed. Cattle are usually grazing forages on remote range land unsuitable for cropping. If they were not out there converting forage into highly nutritious animal protein while at the same time controlling bushfire fodder and encouraging CO_2 fixation by the grasses they consume, the land would go to no other food production purpose. Some suggest that replacing beef with pork and poultry may even *increase* the total demand of arable cropland for animal feed and land use competition between humans and animals. A net gain in cropland is also not obvious if consumption of dairy products is replaced by plant-based food (82% of CA cow feed is unsuitable for human consumption based on nutrient composition, e.g. almond hulls, cottonseed meal), or when monogastric meat is replaced by processed vegetarian meat substitutes.

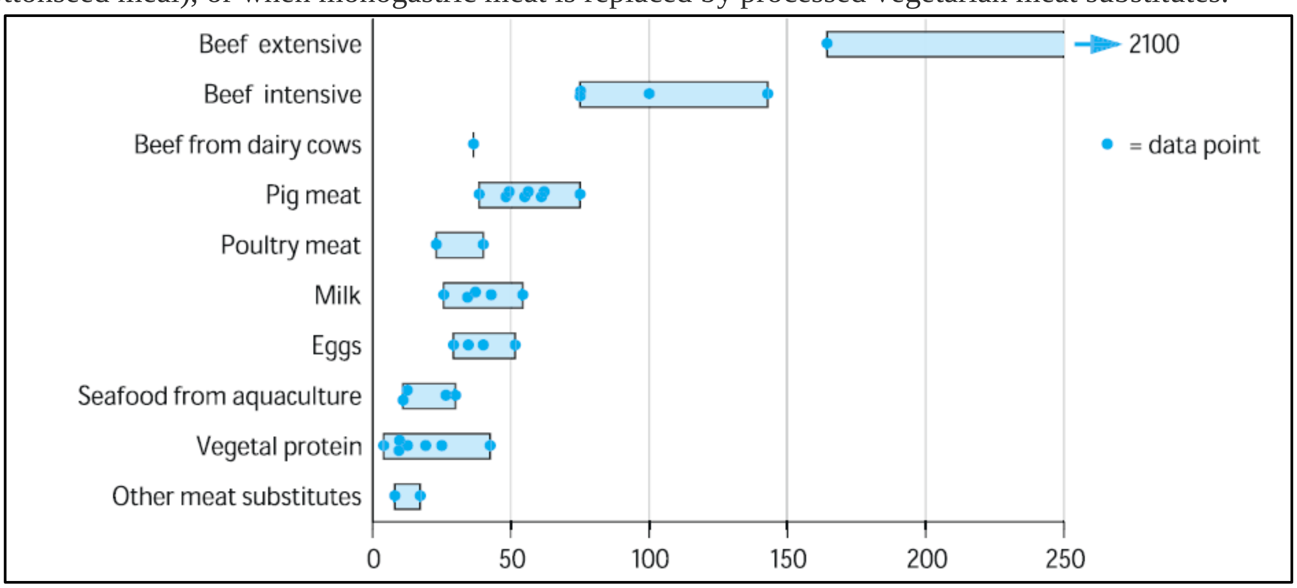


Figure 9. Land use (square meters) per kilogram of protein (7).

Are you confused yet?

These considerations should have impressed upon you the complexity of the answer to the question of food sustainability. In fact, the answer you get will depend upon the question you ask, and the question can be asked in such a way as to put almost any food category on the top or the bottom of the pile. Questions related to nutrition are very different to questions related to "sustainability" – however that might be defined. And questions related to animal protein sustainability can be summarized by the following graph (**Figure 10**). No doubt that simplified it for you! Seriously, there are many factors to consider when making these decisions.

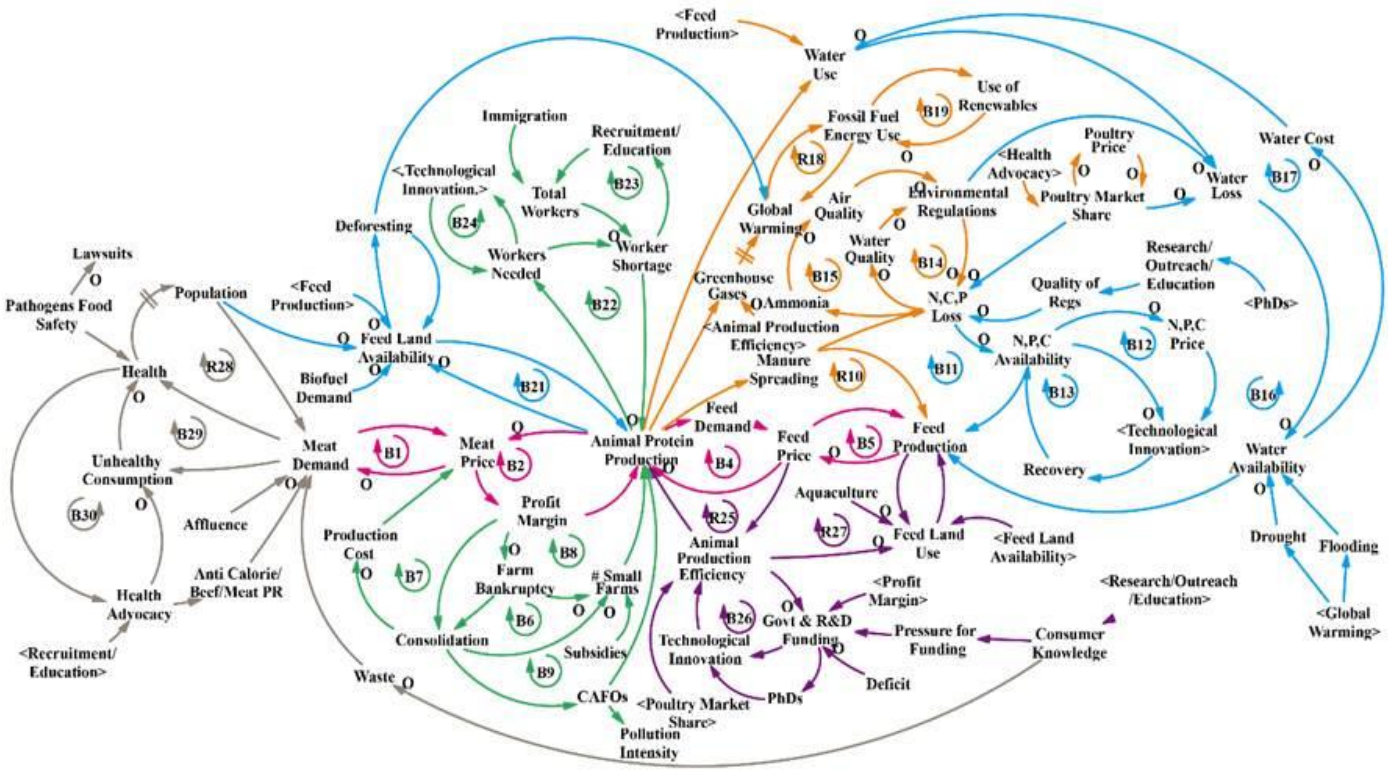


Figure 10. Causal loop diagram identifies the complexity of animal protein systems.

Bigger picture questions about animal protein consumption

Let's consider the bigger picture when it comes to the consumption of animal protein. Livestock production is the world's largest user of land, either directly through grazing, or indirectly through consumption of fodder and feed grains. Globally, livestock production currently accounts for some 36 percent of the gross value of agricultural production (9). In developed countries, this share amounts to half of total production and to almost one-third in developing countries. Developing countries are expected to continue to increase their share in world production so that by 2050 they could account for 70 percent of world meat production (up from 58 percent in 2005/2007) and for 61 percent of world milk production (46 percent in 2005/2007). This projected rise in demand (**Figure 11**) is not being driven by a huge increase in the per capita consumption of milk and meat in the developing world, but rather by an increase in population and income (9).

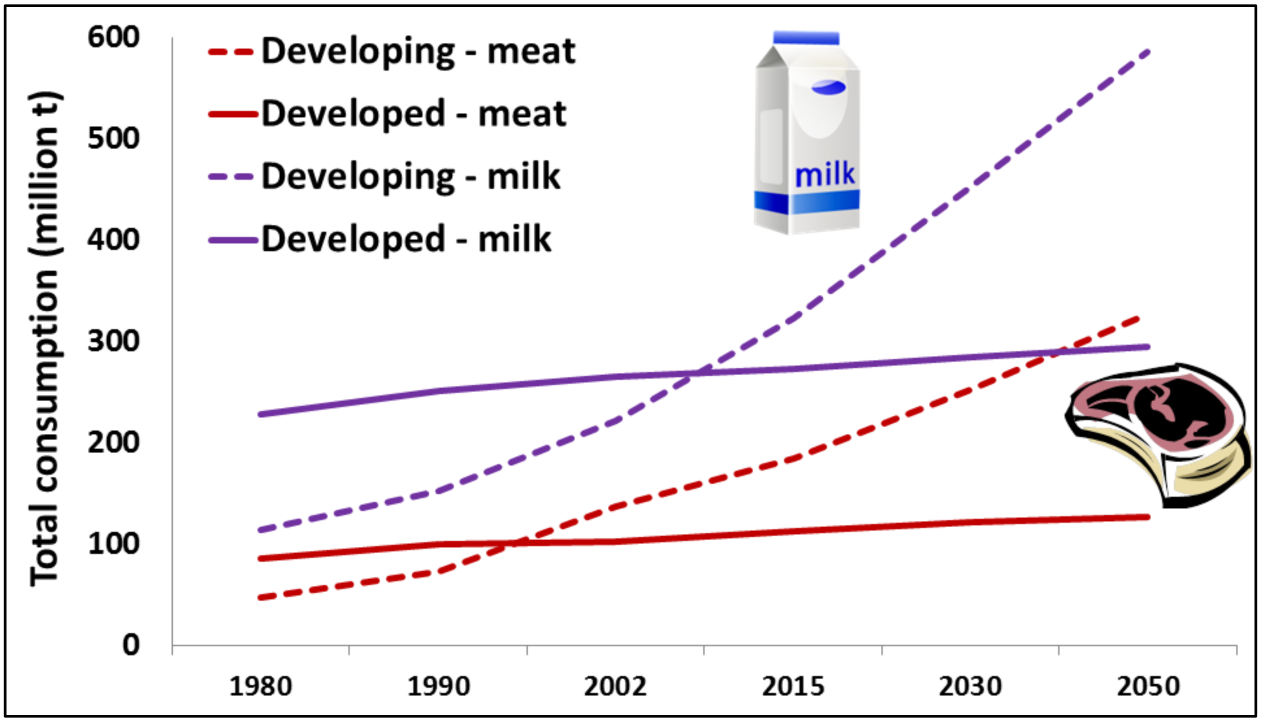


Figure 11. Past and projected trends in consumption of meat and milk in developing and developed countries (9).

Of course, Figure 11 represents what is projected, and does not necessarily represent what will happen. There are many voices out there who argue that this increase may not, or perhaps more stridently, *should not* be allowed to occur. There are three contrasting viewpoints (4) about this projected increase in global demand for animal protein or "livestock revolution", which can be summarized as follows:

1) A production challenge viewpoint, in which case there is a need to change how food is produced by improving the unit efficiency of food production, termed here the 'production efficiency' perspective:

- Also called "sustainable intensification"
- There is a strong strand of optimism/pragmatism underlying this approach; it presents a positive vision of human ingenuity.
- Little attention is paid to potential negatives of overconsumption of animal products in the developed world; rather the importance of meat and dairy to consumers in the developing world is emphasized.
- Tends to focus on consumption patterns of urban populations

With this viewpoint in mind, consider the example of U.S. dairy production. Today there are 9 million dairy cows in the US, 16 million fewer than existed in 1950 (11). Even though cow numbers have decreased dramatically in the past 70 years, milk production nationally has increased 60 percent due mostly to improved genetics as a result of selective breeding programs. If not for these improvements, we would need around 30 MILLION additional dairy cows in the United States to provide our current milk supply. Looked at another way, the carbon footprint of a glass of milk is **2/3 smaller** today than it was 70 years ago (1). Efficiency of agricultural systems is inversely proportional to environmental footprint per unit of production (**Figure 12**).

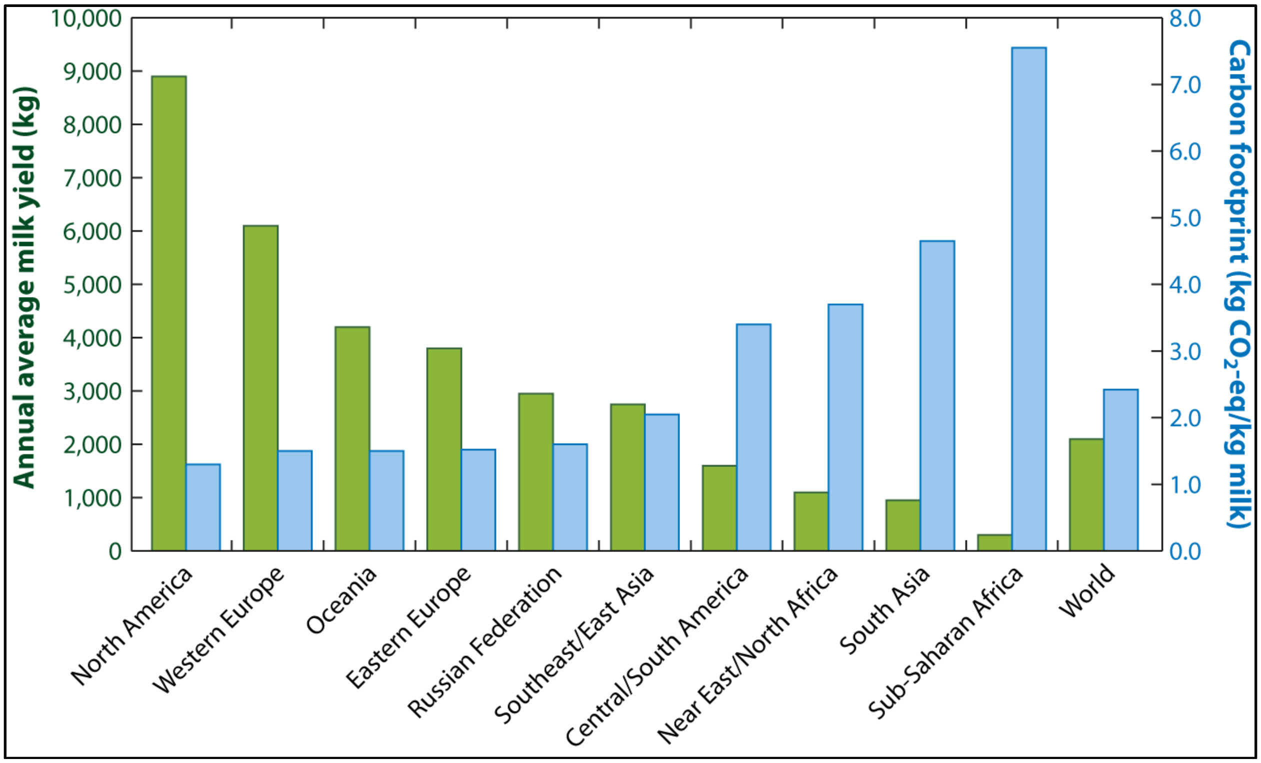


Figure 12. Average annual milk yield and carbon footprint per kg milk across global regions. Milk yield per cow is inversely proportional to carbon footprint/kg milk. Data from FAO (1).

If environmental sustainability was the only consideration, the FAO data could provoke the conclusion that all regions should adopt North American and Western European–style production systems or that dairying should be focused in these areas and discouraged in less-productive regions such as sub-Saharan Africa and South Asia. However, the significant social (both status and nutritional) and economic value of dairying in less-developed regions must not be underestimated. The challenge for global dairy production is to improve productivity and optimize sustainability within each region rather than prescribe one-size-fits-all production systems or management practices.

2) A consumption challenge, which requires changes to the dietary drivers that determine food production (may also include a focus on population growth) and 'demand restraint':

- Conviction that excessive consumption, particularly of high-impact foods such as meat and dairy products, is a leading cause of the environmental and health crises we face. Technological improvements alone will not be able to address the problems.
- This perspective also highlights research findings that reduced consumption of livestock products would actually benefit health.
- Notably, while this perspective strongly emphasizes the diet-related chronic diseases that are associated with animal products and widespread in many parts of the world (particularly cities), it focuses less on the ongoing problem of hunger and micronutrient deficiencies that still affect millions of poor people worldwide, especially in rural communities.

This viewpoint does not recognize the nutritional importance of high quality animal protein in the diets of the rural poor and the other non-nutritional benefits of livestock production in developing countries, which include the following (2):

- Contribute 40% of global value of agricultural output
- Support livelihoods and food security of almost 1 billion people
- Provide food and incomes and consume non-human edible food
- Contribute 15% of total food energy and 25% of dietary protein
- Provide essential micronutrients (e.g. iron, calcium) that are more readily available in meat, milk, and eggs that in plant-based foods
- Are a valuable asset, serving as a store of wealth, collateral for credit, and an essential safety net during times of crisis
- Are central to mixed farming systems; consume agricultural waste products, help control insects and weeds, produce manure for fertilizer and waste for cooking, and provide draft power for transport
- Provide employment, in some cases especially for women
- Have a cultural significance as the basis for religious ceremonies

It is thought that humankind's association with domesticated animals goes back to around 10,000 BC, a history that is just about as long as our association with domesticated plants. What is in store for this association in the coming century is far from clear, although it is suffering from stress and upheaval on several fronts. The global livestock sector may well undergo radical change in the future, but the association is still critical to the wellbeing of millions, possibly billions, of people. In many developing countries and at this stage in history, it has no known, viable substitute.

3) A socio-economic challenge viewpoint, considers both production and consumption and sees the problem as one of "imbalance"
Many within this perspective advocate a central role for smallholders (particularly women) in farming a diverse range of indigenous crops and livestock breeds for local markets:

- More localized, diverse systems are seen as better able to deliver the full range of micronutrients needed for good health than global supply chains which produce and distribute a simplified range of processed, energy and fat-dense commodities.
- Looks beyond the nutritional role of meat and dairy to consider the role that livestock plays in the livelihoods of poor people, and the effect that this in turn has upon health
- It can romanticize smallholder production and many people with this perspective tend to argue for organic or "agro-ecological" approaches

Each of these three viewpoints has insights to offer, as well as weaknesses and inconsistencies. These may sometimes go unrecognized by stakeholders, who are too immersed in a particular frame to recognize its shortfalls or the merits of an alternative approach.

SUMMARY

There is no one sustainable source of protein, and depending upon the question that is being asked (e.g. carbon emissions/water use/land use/energy use **per** calorie/unit weight/unit protein), different food products will look like the "most sustainable" choice. There are also ethical and religious concerns around animal welfare and/or consuming meat and/or animal products (e.g. eggs, milk). Often there are direct conflicts between what is perceived as the most sustainable production system. Is it the one that best protects animal health/welfare, the one with the lowest environmental footprint per unit of product, or the most efficient? As with all dietary decisions there are tradeoffs among the various pillars of sustainability, and consumers will need to make the choices they consider to be best for their particular family values, budget, and circumstances.

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