

Quantification of the environmental impact of different dietary protein choices¹⁻³

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ABSTRACT Quantitative environmental evaluations of meat, fresh vegetables, and processed protein based on soybeans suggest that the environmental burden of vegetarian foods is usually relatively low when production and processing are considered. The environmental comparison of cheese varieties made from cow milk and directly from lupine and the evaluation of energy inputs in fish protein and vegetable protein also suggest an environmental advantage for vegetarian food.

In the evaluation of processed protein food based on soybeans and meat protein, a variety of environmental impacts associated with primary production and processing are a factor 4.4→100 to the disadvantage of meat. The comparison of cheese varieties gives differences in specific environmental impacts ranging between a factor 5 and 21. And energy use for fish protein may be up to a factor 14 more than for protein of vegetable origin. Assessment suggests that on average the complete life cycle environmental impact of nonvegetarian meals may be roughly a factor 1.5–2 higher than the effect of vegetarian meals in which meat has been replaced by vegetable protein. Although on average vegetarian diets may well have an environmental advantage, exceptions may also occur. Long-distance air transport, deep-freezing, and some horticultural practices may lead to environmental burdens for vegetarian foods exceeding those for locally produced organic meat. *Am J Clin Nutr* 2003;78(suppl):664S–8S.

KEY WORDS Life cycle impact assessment, environmental impact, meat, cheese, fish, soybeans, processed protein, vegetables, vegetarian meals

INTRODUCTION

Technologic advances have allowed dramatic output increases in modern agriculture. With these improvements, the environmental impact of food production and consumption has also increased (1–7). Humankind currently appropriates an estimated 32–55% of all primary production by photosynthesis on land, and the food sector is the main factor in this appropriation (2–5). Human appropriation of biomass claims large land areas and has pushed back nature (2–5). The pushing back of nature in turn negatively affects services rendered by nature such as biogeochemical cycling and degradation of pollutants (8). The expansion of agriculture has also substantially increased the extinction rate of species (5). Furthermore, by now about half of usable fresh water is appropriated by humankind; food production and consumption again dominate this appropriation (4, 5).

Another important environmental burden is energy use for food production and consumption. In Western industrialized countries, energy use in the food sector is large in both relative and absolute terms. In the United States, Sweden, and the Netherlands, the food sector absorbs about 17% of total energy use. If, for example, the rest of the world paralleled the energy intensiveness of the US agricultural production system, proven worldwide mineral oil reserves would last about 12 y in supplying energy for food production and consumption alone (1, 5). Other aspects of food production and consumption in industrialized countries are currently wasteful. Nitrogen efficiency in food production and consumption, for instance, is low. In the case of Norway, 90% of nitrogen inputs in agriculture are lost somewhere on their way to the kitchen (7). This has a negative effect on water quality and ecosystems (4, 7).

The negative environmental impacts of food production and consumption are expected to grow worldwide in the near future. For instance, extrapolation of current trends suggests that in the next 50 y, 10⁹ hectares of nature may be converted to agricultural land, whereas emissions of nitrogen and phosphorous compounds and of biocides may increase by a factor of 2.4–2.7 (4).

Many scientists and even policymakers have begun to question the sustainability of agriculture as practiced today (9–11). Particular skepticism has been directed at supporting the increased demand for animal products in the diet of the economically advantaged persons of the world (12–14). Throughout the world, there appears to be a direct link between dietary preference, agricultural production, and environmental degradation (15, 16). Understanding such connection is of critical importance if present and future food security is to be ensured while long-term sustainability and integrity in agriculture are achieved.

Although improved agricultural practices are important in limiting the environmental impact of the food sector, the potential contribution of changes in dietary choices should not be neglected

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(17, 18). Gussow (19) issued a call for research permitting direct comparisons of the ecologic consequences of one diet over another. Several associations have been suggested (16, 20, 21). The main purpose of this article is to present data and methods from recent studies conducted in Europe that can be used for quantitative comparisons of the environmental impact associated with animal and plant products in the diet.

LIFE CYCLE IMPACT ASSESSMENT TECHNIQUES

Life cycle impact assessment (LCIA) techniques offer promise for evaluating diet choices environmentally and quantitatively. LCIA focuses on relative comparisons of whole systems over a product's life, relating each system to a diverse range of environmental impact categories (22). LCIA may include a weighting method whereby a single score, or ecoindicator, is derived for the total environmental impact based on the calculated effects. The ecoindicator of a process is thus a number that indicates the environmental impact based on data from a life cycle assessment—the higher the ecoindicator, the greater the environmental impact. Specifically, LCIA traces the environmental impacts associated with food from cradle (generation of resources) to grave (final disposal) through the stages of the production-consumption-disposal chain. These stages are primary production (agriculture, fishing), processing, retail, shopping, storage at home, cooking, dishwashing, and waste disposal. Many of these stages include transportation as well.

A number of comparative LCIA studies have been carried out for kinds of food and meals that are relevant for diet choices involving vegetarianism (6, 17, 23, 24).

It should be noted that outcomes of these LCIA studies are not perfect representations of real-life environmental impacts. Important effects of agriculture such as effects on quality of agricultural soils and the direct effect on biodiversity are neglected in current LCIA studies. Other deficiencies are the limited reliability of data used and the fact that outcomes only partially reflect real-life environmental impacts (25). Thus, comparative LCIA studies give only rough indications of relative environmental impacts.

LCIA studies suggest that the differences between animal products and vegetarian alternatives are most marked at the level of primary economic production (agriculture, fishing) and, in some cases, with respect to processing of foodstuffs. Therefore, the focus of this article is agriculture and fishing and, where applicable, the processing stage.

Using data from LCIA studies and other sources, we evaluated the environmental impact of vegetarian and nonvegetarian diet choices by comparing a number of input-output parameters (effects) related to primary production. Inputs and nonproduct outputs will be compared for the same output of protein (in grams). All these evaluations will deal with foods as they are currently produced in Western industrialized countries. First we compare (average) meat and a processed protein food based on soybean protein. A second comparative evaluation considers (average) meat and (average) fresh vegetables. Third, we compare cheese made from cow milk and lupine-based cheese. A fourth comparison evaluates fossil energy inputs per gram protein in fish and in products of vegetable origin. Finally, we consider quantitative differences at the level of ready-to-eat foods, concerning the full production-consumption-disposal chain of vegetarian and nonvegetarian meals.

TABLE 1

Relative environmentally relevant differences between meat protein and a processed protein food based on soybeans (industrial countries)¹

Environmentally relevant effect	Effect of processed protein food based on soybeans	Relative effect of meat protein production
Land use	1	6–17
Water requirement	1	4.4–26
Fossil fuel requirement	1	6–20
Phosphate rock requirement	1	7
Emission of acidifying substances	1	>7
Emission of biocides	1	6
Emission of copper	1	>100

¹Effect refers to identical amounts of protein. The effect of soybean protein-based food is (arbitrarily) given the value of 1.

COMPARISONS

Meat protein compared with processed soybean protein

Meat in Western industrialized countries is to a large extent produced on the basis of feed grains and soybeans. Thus, the environmentally relevant effect of meat production comprises both animal husbandry and the growth of feed grains and soybeans that are eaten by the animals involved. The following inputs in the production process are discussed below: land, water, fossil fuel, and phosphate rock. Nonproduct outputs that will be considered are acidifying substances (eg, sulfur oxides, nitrogen oxides), biocides, and copper. **Table 1** summarizes the environmental differences between food based on soybean protein and food based on meat protein.

Land requirement

On average, 10 g of vegetable protein are needed to generate 1 g of animal protein (26). There are differences between different types of meat production. For broiler production, the protein conversion efficiency is about 18%, for pork about 9%, and for beef about 6% (26). This is reflected in differences in land requirements. Compared with soybean production, land requirements are roughly a factor 6–17 larger for meat protein production.

Water requirement

Water is an increasingly scarce natural resource (5). Water requirements for meat protein production are higher than for the production of vegetable protein. Differences are large (about a factor 26) when rain suffices for production of feed and smaller (roughly a factor 4.4) when intensive irrigation is necessary (27).

Fossil fuel requirement

Fossil fuels are virtually nonrenewable natural resources. Differences in fossil fuel requirements for vegetable protein and meat protein production strongly depend on the intensity of agriculture. Wide variations in fossil fuel use are reported in the literature. Depending on the relative intensities of agricultural practices and attributing all energy inputs to the production of foodstuffs, the efficiency of fossil fuel use may be a factor 2.5–50 better for vegetable proteins, if compared with animal husbandry (23, 24, 26–28). In European countries, this difference will usually be a factor 6–20 to the advantage of soybean-based protein food (24, 27, 28).



TABLE 2

Environmental evaluation of the (primary) production of meat and fresh vegetables in Switzerland¹

Foodstuff	Score
	<i>ecopoints/kg</i>
Meat, integrated agriculture	0.080
Fresh vegetables, integrated horticulture	0.054
Meat, organic	0.043
Fresh vegetables, organic	0.016

¹Based on reference 23.

Phosphate rock requirement

Phosphate rock is a virtually nonrenewable natural resource that finds its way into agriculture via synthetic fertilizer and feed additives. Phosphate emissions associated with agricultural use may have a eutrophying effect on nonagricultural soils and surface waters that may in turn reduce biodiversity (4). Input of phosphate rock in meat protein production is estimated to be 7 times higher than for the production of soybean-based vegetable protein (27).

Emission of acidifying compounds

Acidifying compounds such as sulfur oxides, nitrogen oxides, and ammonia may change the pH of poorly buffered surface waters and soils. In practice, critical loads of acidifying compounds are exceeded in parts of North America, Asia, and Europe (27). This in turn may have a negative effect on biodiversity and on water quality (7, 27). The output of acidifying substances expressed as acidification potential was found to be at least 7 times larger for meat protein production than for a processed protein food based on soybeans (27).

Emission of biocides

Biocides are applied to crops (pesticides), used in animal husbandry (disinfectants and pesticides), and used in the production of processed protein foods (disinfectants). Because biocides also tend to have an effect on nontarget species, there may be negative effects on ecosystems and human health (4, 27). The use of biocides in meat protein production was found to be 6 times the corresponding use in growing soybeans and converting soybean protein into a processed protein food (27).

Emission of copper

Copper finds its way into agricultural production as a trace element in fertilizer and as a feed additive. Such dissipative use leads to copper pollution of soils. This in turn may have a negative effect on some farm animals and on a variety of plants (29). A study comparing meat protein with processed protein food based on soybeans suggests that the relative emission of copper related to meat production is at least 100 times the emission associated with the production of vegetable protein (27).

Meat compared with fresh vegetables

Jungbluth et al (23) compared meat with fresh vegetables, averaging the environmental impacts of a number of different kinds of meat and fresh vegetables in line with actual consumption patterns in Switzerland. They did so for organic agriculture and integrated agriculture as it is practiced in that country. In contrast to conventional farming methods relying on extensive use of natural resources, organic farming practices include controlling pests

TABLE 3

Relative environmentally relevant differences between cheese made directly from lupine and cheese made from cow milk from intensive animal husbandry (primary production and processing)¹

Relevant effect	Cheese made directly from lupine	Cheese made from cow milk (intensive animal husbandry)
Land requirement	1	5
Environmental burden ²	1	9–21

¹Effect refers to identical amounts of cheese. The effect of lupine-based cheese is (arbitrarily) given the value of 1. Based on reference 31.

²Emissions of ecotoxic, eutrophying, and acidifying compounds.

naturally, rotating crops, and applying animal and green manures. In integrated farming, organic and conventional methods are combined, thereby reducing inputs of biocides and nutrients. Jungbluth et al made inventories of energy-related emissions, emissions of nutrients and pesticides, and emissions of climate-forcing “greenhouse gases” that are unrelated to energy production. They used ecoindicator methodology (30) to weigh a number of environmental impacts on ecosystems and human health, leading to an overall effect expressed in ecopoints. The score in ecopoints increases when the estimated environmental burden increases. The results of the comparative evaluation of environmental impacts caused by primary production (agriculture) are in **Table 2**. The overall environmental impact appears to be practice dependent. Integrated farming scored ahead of organic farming, hence representing a greater environmental burden. When agricultural practices are similar, 1 kg of fresh vegetables is environmentally preferable to 1 kg of meat. Also note that scores for organic meat, and vegetables produced through integrated horticulture, were similar, indicating in this case a similar environmental burden for the practices.

Cheese based on cow milk compared with lupine-based cheese

Cheese produced directly from lupine in Western Europe has been compared with cheese made from cow milk (31). The focus of this study was on land use and the emissions of major pollutants. This study was not peer reviewed but is in line with requirements of the International Organisation for Standardization (32). It was found that the land requirement for lupine-based cheese production was 0.02 ha 100 kg⁻¹y⁻¹, whereas 0.1 ha was needed for the same amount of cheese based on intensive cow milk production.

As to the emissions of ecotoxic, acidifying, and eutrophying compounds, the environmental burden was calculated by using a set of weighing factors developed for LCIA (30) that Jungbluth et al (23) also applied. The environmental burden associated with the emissions studied was a factor 9–21 lower for the production of cheese directly from lupine than for cheese production based on cow milk. **Table 3** summarizes the environmental differences between cheese varieties based on cow milk and lupine.

Fish protein compared with vegetable protein

The previous comparisons dealt with terrestrial products, accounting for about 99% of human food. The remaining 1% comes from aquatic systems (5). Fish, the major product from aquatic systems, is predominantly caught. This leads to differences in types of effect when compared with agriculture.

While depletion of fish stocks is a major problem in fishing (33), there is no equivalent resource problem in agriculture. In



contrast to agriculture, in fishing there is no application of fertilizers and pesticides. Because the only effects common to agriculture and fishing relate to the use of fossil fuels, our discussion concentrates on the use of these fuels in the Western European context.

In Western Europe, fish is predominantly caught by trawlers and subject to diminishing returns (34). There, trawler fishing now requires about 3.4 L fuel oil per kilogram fish (34). Other types of fishing, such as gillnet fishing, require substantially less oil—about 0.4 L/kg fish (17).

From available data on fossil fuel intensities of fishing by trawler and crop rearing in Western Europe (27, 28, 34), it can be concluded that, per gram of protein, the input of fossil fuels for catching fish may be up to roughly 14 times larger than for the production of vegetable protein. If fish is caught in gillnets, energy use per gram of protein produced may be about 65% larger for fish protein than for vegetable protein. If the comparison is extended to processing, differences may be even more marked, as fish conservation may increase the input of fossil fuels by 20–44 MJ/kg (17).

Increasingly, fish is produced by aquaculture—for example, in fishponds or land-based tanks. The environmental impacts thereof in terms of area requirements and the release of biocides and nutrients (eutrophying substances) may be of the same order as those of conventional animal husbandry with the same intensity of production (35). Aquaculture of carnivorous fish fed on fishmeal probably poses a relatively heavy environmental burden (35). Moreover, aquaculture may be associated with risks of changing the gene pool in wild populations (35, 36), a problem usually not encountered in current conventional animal husbandry.

Differences between vegetarian and nonvegetarian meals

The data presented so far suggest that vegetarian alternatives for meat, cheese, and fish may have a relatively low environmental impact when primary production and processing are considered. Although the relative values for environmental impacts presented so far cover a part of the “cradle to grave” chain for foodstuffs, the environmental burden associated with logistics, packaging, refrigeration, cooking, and some types of processing has not been included. When other elements of the production-consumption-disposal chain are included, some differences become less marked. This especially holds for the relative inputs of fossil fuels, though one may note that energy differences of up to a factor 20 may occur regarding ready-to-eat vegetarian and nonvegetarian foodstuffs (17).

Van der Pijl and Krutwagen (24) have studied the environmental impacts associated with the full production-consumption-disposal chain of an average Dutch conventional meal and an average vegetarian meal in which meat was replaced by a soybean protein-based product. Their study was not peer reviewed, but it is in line with requirements of the International Organisation for Standardization (32). Van der Pijl and Krutwagen considered differences as to land use, pesticide use, fertilizer use, and fuel use and evaluated different types of environmental impacts, including resource depletion, land requirements, and several types of pollution-related effects, including global warming, human toxicologic and ecotoxicologic effects, formation of photooxidants, acidification, and eutrophication. They concluded that the overall environmental impact was roughly a factor 1.5–2 to the advantage of the vegetarian meal (24).

DISCUSSION

Available data presented here suggest that on average, and in several specific cases, vegetarian food has an environmental

advantage as evaluated by present LCIA methodology. It should be noted, however, that this conclusion does not necessarily extend to all specific instances.


As shown by Jungbluth et al (23), long-distance transport of food by airplanes, as evaluated by LCIA methodology, may have a very large effect on the overall environmental burden of food. They found that long-distance air transport of 1 kg food has roughly the same environmental impact as the primary production of 1 kg organic meat. So vegetarian food flown in by plane may well be at an environmental disadvantage if compared with locally produced organic meat. Jungbluth et al (23) also show that deep-freezing of vegetables is associated with relatively large environmental impacts. Their study suggests that deep-frozen vegetables may have environmental burdens exceeding the effect associated with the primary production of organic meat. Carlsson-Kanyama has shown that vegetarian food consumption patterns that include exotic items may be more polluting than meals with meat ingredients produced locally (16).

Furthermore, there are substantial differences in environmental impacts between different primary production systems. The environmental burden of crop production associated with the input of agrochemicals or emissions of pollutants differs between conventional, integrated, and organic agriculture. In Central Europe, differences are on average up to about a factor 2 per kilogram crop (23, 37). Organic agriculture was found to have the lowest effect and also has advantages as to soil quality and biodiversity, aspects currently not covered by LCIA (37–39), though it is at a disadvantage regarding land requirements because crop yields tend to be lower than in conventional production systems (38, 39).

Environmental differences of that magnitude associated with production practices do not affect the environmental preference for vegetarian foods in 2 of the comparisons made above (meat protein compared with soybean-based protein, and cheese based on cow milk compared with cheese based on lupine). For fresh vegetables, however, the situation is different. Fresh vegetables from integrated horticulture do somewhat worse, environmentally, than organic meat. Also, horticulture in fossil fuel-heated greenhouses is associated with a relatively large environmental burden (23). In the study of Jungbluth et al (23), primary production of organic meat has an environmental advantage over that of vegetables grown in greenhouses. Thus, long-distance air transport, deep-freezing, and some horticultural practices for producing fresh vegetables may lead to environmental burdens for vegetarian foods exceeding those of locally produced organic meat.

The concept of sustainable food systems at lower environmental, social, and economic costs is achieving worldwide currency in the agroecologic and international development communities (40). With regard to food consumption, long-term environmental sustainability and integrity will become practically impossible because of current population growth. Demand for food can be reduced in part through improved technology and methods that result in more efficient and environmentally sound agricultural practices. Of considerable interest in this respect is the emergence of precision agriculture, which promises substantially lower environmental impacts (41).

In comparisons between diet choices, it has been implicitly assumed that vegetable protein products are an adequate replacement for meat and fish in the diet. To the extent that some may question this assumption, adaptations can be introduced, such as lowering the phytate content of vegetable proteins during processing or adding trace elements or vitamins. Such adaptations are expected to have a very limited environmental impact.

Ideally, people should always be allowed to choose the diet they want, but under the current pressures imposed by overpopulation, resource scarcity, and overconsumption, absolute dietary freedom could soon, lamentably, become a luxury. Diet matters (15). Flexibility and opportunism in the diet can be very valuable in reducing the demand for food, especially as humans attempt to transition to sustainable societies. Encouraging individuals to eat more efficiently (ie, descend) on the food chain, consuming less meat and more plant-based foods, may be one of the types of measures that will lead to increased sustainability and reduced environmental costs of food production systems (18). 

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