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Building Block

What is feed-food competition?

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Why should you read this building block?

This building block explores key statistics about competing uses for food system resources, focusing on the use of land, crops and wild fish for feeding humans or feeding livestock – a trade-off known as feed-food competition. It also outlines different ways in which people interpret these figures and sets out how these differing perspectives link to broader debates about what we should eat and how we should produce food, particularly concerning what role (if any) livestock should play in the global food system.

Definitions

Feed-food competition: the tensions and trade-offs between using edible crops and other resources to either feed people directly or feed livestock.

Bioavailability: the extent to which nutrients that are ingested can be utilised by the body.

Externality: an economic cost or benefit incurred or received by a third party to a transaction (i.e. by an individual or group that is not the buyer or seller), such as the cost of cleaning up pollution. Negative externalities refer to an overall cost to society, while positive externalities refer to an overall benefit to society. The cost of externalities can be internalised.

Feed conversion ratio: is a ratio measuring the efficiency with which farmed animals convert animal feed into the desired output (e.g. meat, milk, eggs, and so forth). The ratio is calculated by dividing the mass of feed inputs (e.g. grass, soymeal, cereals, etc.) by the mass (or food energy value) of outputs. A related concept is feed efficiency (the inverse of the feed conversion ratio).

Internalised cost: incorporation of the cost of an externality into the cost of an economic transaction, such as through a tax to cover the costs of rectifying pollution.

Nutrient profiling: classifying or ranking foods according to their nutritional composition for reasons related to preventing disease and promoting health. Algorithms for this process are known as nutrient profile models.

Opportunity cost: an economic concept referring to the benefits forgone by choosing one of multiple, mutually exclusive courses of action.

Rewilding: the intentional restoration of natural ecosystems, sometimes supported by the reintroduction of particular native species (particularly predators such as wolves) to areas where they are no longer present.

1. What is feed-food competition and why does it matter?

"Feed-food competition" generally refers to the tensions and trade-offs between two alternative uses for edible crops: direct consumption by humans versus feeding livestock[1] (this meaning is illustrated by the red box in Figure 1). The term is therefore closely linked to debates about the increasingly disputed role of livestock in the food system.

However, feed-food competition sits within a wider system of competing end-uses for the many different resources available to the food system, the wider economy and human society overall. These resources include land, wild fish, water, labour, capital and ***ecosystems services*** (such as the ability of ecosystems to absorb, dissipate or neutralise pollutants such as greenhouse gas emissions, nitrogen run-off or pesticides)[2].

Resources can be used not just for human food and livestock feed but also for many other competing purposes. Land, for example, can either be used for agriculture, nature conservation, ***rewilding*** (conversion back to natural ecosystems such as forest or grassland), or used for non-agricultural purposes such as wind farms, solar panels, parks, golf courses, roads or housing[1]. Agricultural land, depending on its quality, can be grazed or cropped. Human-edible crops can be consumed directly by people, while both human-edible crops and human-inedible crops can be fed to livestock or pets or used for biofuels, fibres and other industrial purposes[2]. Capital can be invested in existing industries or emerging sectors (such as cultured meat), while people can work in different countries and economic sectors.

The allocation of resources between all these possible uses is often determined by which end use is most profitable and is therefore driven by economic forces such as changing income levels, consumption preferences, the price of land, wage levels and government taxes and subsidies. Other factors influencing resource allocation include the growth of the human population, differing cultures and values, environmental policies, skills that people have in the workplace, migration policies, demand for energy (e.g. for private or public transport) and technological developments (such as automation or sustainable intensification).

With finite resources available to the food system, each use has ***opportunity costs*** and trade-offs relative to other options in terms of the environmental, social and economic impacts and benefits produced. For example, biofuel production can increase food prices and ***land use***. More rarely, some synergies exist between options. Biofuel production, for instance, generates waste products that can be fed to livestock[2]. These impacts and benefits can either be caused directly or happen through interactions with other elements of the food system, economy, society or environment.

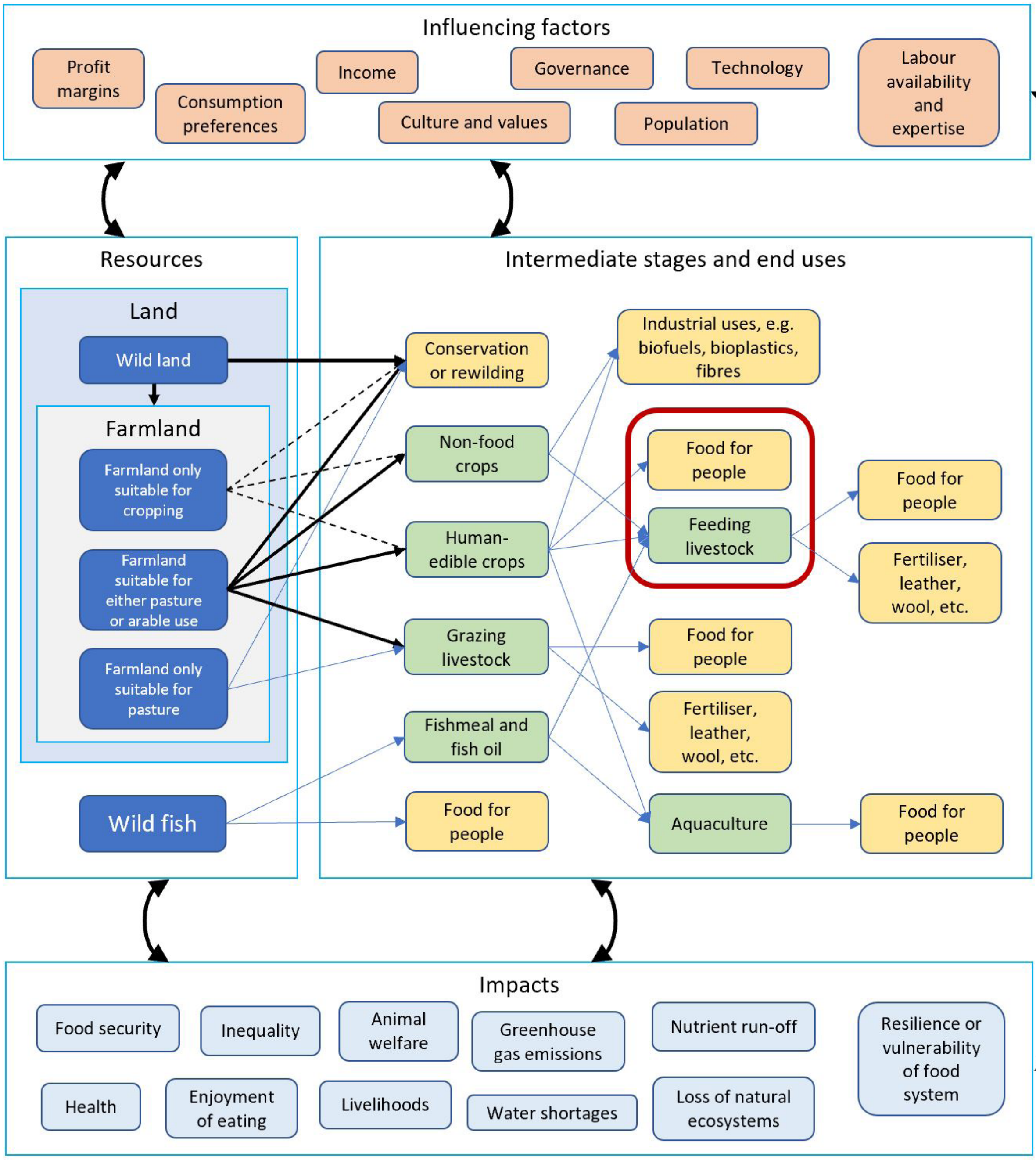

Figure 1: A non-exhaustive overview of some competing end-uses of land, crops and wild fish. For ease of viewing, the figure does not include all resources (for example, water, labour and capital are excluded) nor all possible end-uses, influencing factors or impacts (for example, land used for urban areas and food for pets are not included). Resources, end-uses, influencing factors and impacts can all influence one another, as shown by the curved black arrows. Graphic produced by the FCRN.

2. How are food system resources currently used?

This section reviews key statistics on current resource use and the extent to which feed production and food production compete.

Land

How much land is farmed?

There are large uncertainties as to how land is used worldwide. The ***IPCC*** (Intergovernmental Panel on Climate Change)[3] reviewed several sources to reach its best estimates, shown below. There are 13 billion ha of ice-free land worldwide, of which one third (4.3 billion ha) is permanent grazing or crop land. A further 2.0 billion ha of grazing land is not dedicated exclusively or permanently to grazing: rather, it is unforested land used for multiple purposes including seasonal grazing, rough grazing (i.e. grazing on land that has not been ploughed, fertilised or seeded), hunting, gathering wild products and collecting firewood. While estimates differ (based on differing observation methods and definitions, cropland covers between 1.6 and 1.9 billion ha, while grazing land (both permanent and multi-use) occupies between 3.9 and 6.2 billion ha. Thus, between 42% and 62% of ice-free land is used for agriculture (this figure excludes forest plantations).

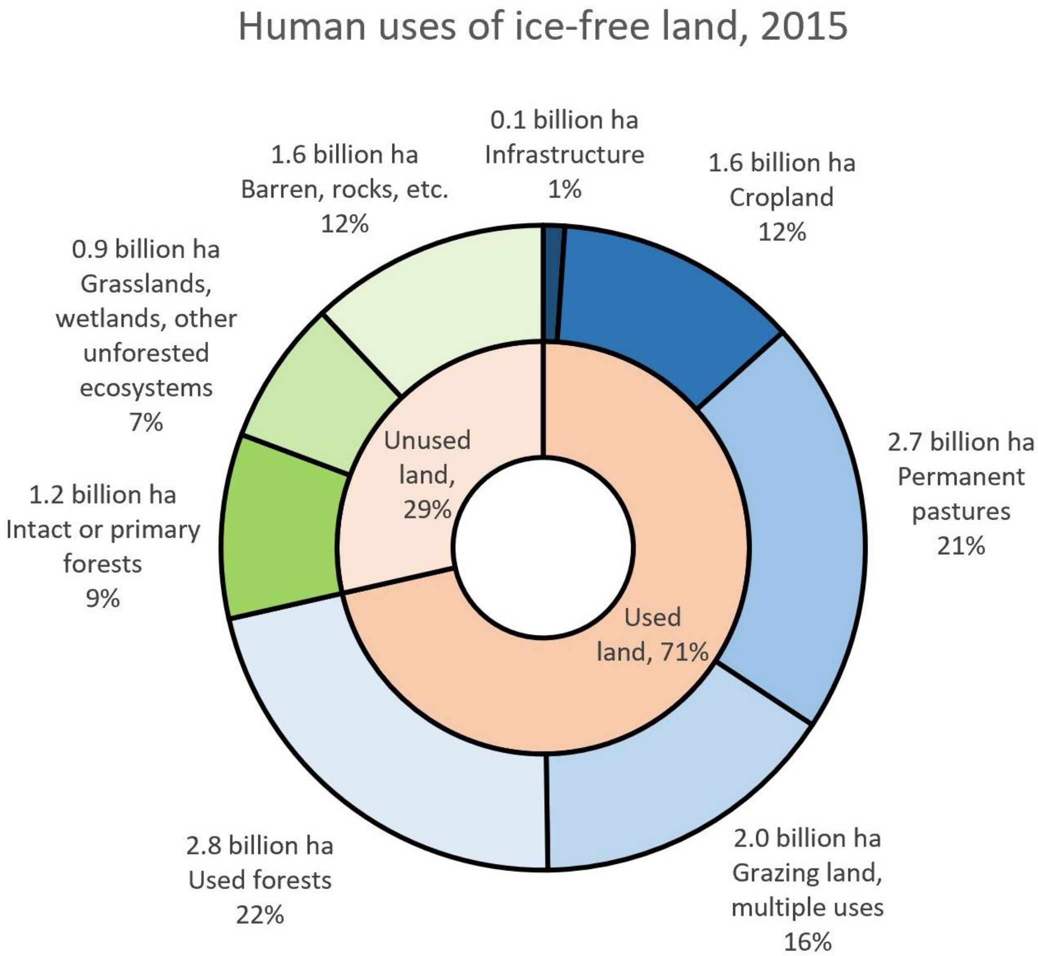

Figure 2: Global uses of ice-free land, circa 2015, best estimates. Total ice-free area is 13 billion ha. Figure produced by the FCRN; data from Table 1.1 of IPCC (2019)[3].

On which land do feed and food production compete?

Feed-food competition is arguably present wherever land is used to produce either feed or food, or even in areas of natural ecosystems that are liable to being converted to agriculture. However, the extent of direct feed-food competition can be defined as the area of land that is capable of producing crops for direct human consumption, but which is currently used to grow feed crops or graze livestock.

As indicated below by the red arrows, estimates of those land areas vary between sources (the agricultural land-use estimates of the IPCC[3] are shown in the left column for context). Gladek *et al.* (middle column) estimate that one third of cropland (0.5 billion ha, or 8% of the IPCC's estimate of total agricultural area) produces feed crops for livestock.

Mottet *et al.* (right column) similarly estimate that 0.4 billion ha of cropland produces feed for livestock in a way that competes with food crop production (including production of edible feed crops, oil seed and oil seed cakes, and inedible fodder crops). They additionally class 0.7 billion ha of grassland as competing with food crops for land (right column below), because this area is suitable for cropping despite being currently grazed, making a total of 1.1 billion ha or 17% of the IPCC's estimate of agricultural land area that produces livestock when it could produce crops. However, converting grassland to cropland can release carbon from soils to the atmosphere and impact upon ***biodiversity*** – these impacts, although not discussed further here, are nevertheless important and would need to be factored into any land use decision making[1].

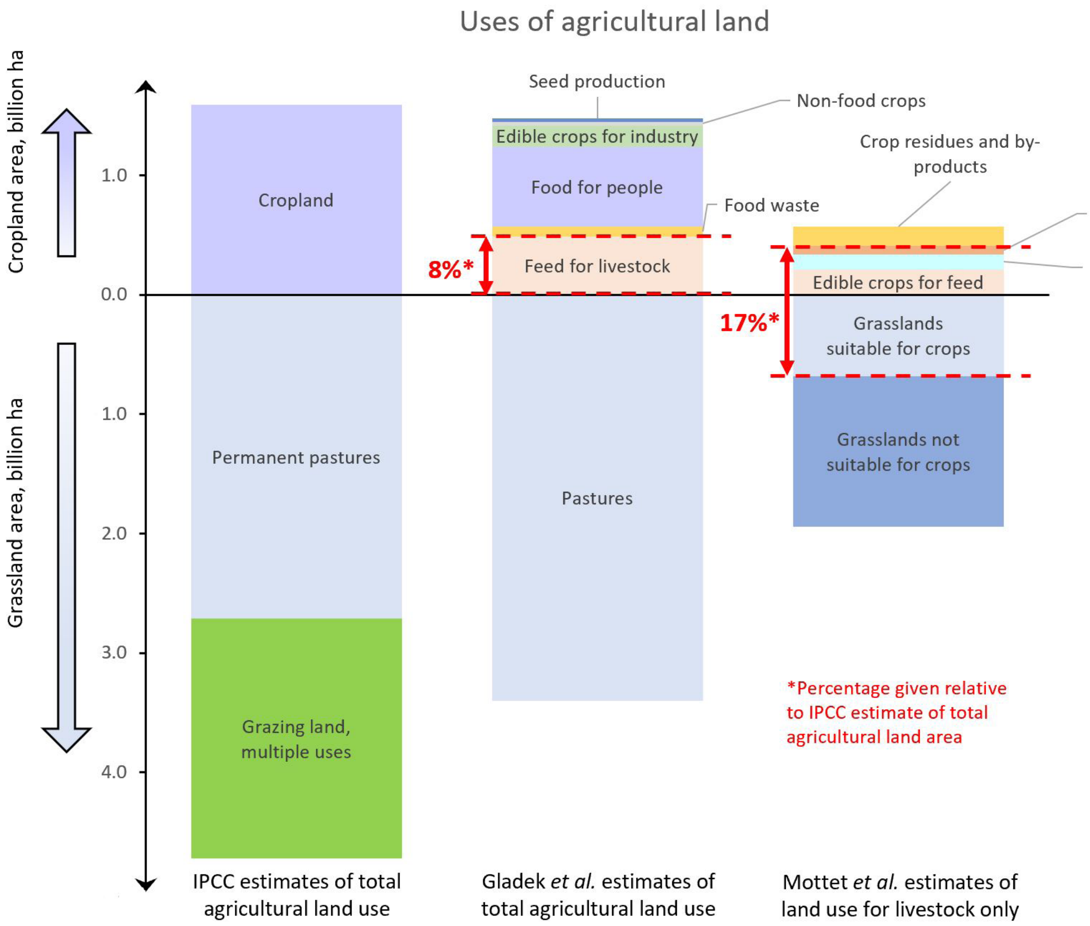

Figure 3: Different estimates of total agricultural land use (IPCC[3] and Gladek *et al.*[4], both for the year 2015) and land use for livestock production only (Mottet *et al.*[5], for the year 2016). Areas of cropland are shown above the horizontal axis, and areas of grassland area shown below. The red arrows indicate areas of land where livestock feeding could be considered to compete with the production of food for direct human consumption. The IPCC does not estimate the area of cropland used to produce feed in the year 2015, but it does refer to Foley *et al.*[6], who estimated that 0.35 billion ha of cropland produced animal feed in 2000 (this figure is not shown on the diagram because of the 15 year difference between the estimates). Beyond their estimates of the area of land grazed, Mottet *et al.* suggest that a further 1.5 billion ha of grassland area is marginal and has no livestock on it (this area is therefore not shown above), which explains why Mottet *et al.* estimate a lower grazing area than Gladek *et al.* and the IPCC. The category "feed for livestock" in the estimates of Gladek *et al.* does not include any land implicated in the production of oilseed cake, which Gladek *et al.* treat as a by-product of edible oil production. Figure produced by the FCRN.

Crops

Feed-food competition applies to crops as well as land, since human-edible crops can either be fed directly to people or fed to livestock.

As shown in Figure 4 (middle and right columns), Alexander *et al.*[7] estimate that feed crops and processed feed such as oilseed cakes (both of which can be considered to compete with feeding people directly) account for 27% of livestock feed and 30% of crop consumption, by dry mass. For comparison, humans consume 45% of crops as food. On the face of it, then, the quantity of crops available for direct human consumption could rise by two-thirds if feed crops and processed feed were no longer fed to livestock. See also the section "Quantity of food produced" below.

A further 12% of crops is used for non-food purposes, including biofuels (for further discussion on non-food uses of crops, see What is food loss and food waste?).

Mottet *et al.*[5] provide similar estimates to Alexander *et al.* for the absolute quantities of edible crops consumed by livestock (left column below). However, their estimates of livestock feed include a larger quantity of crop residues and by-products. They therefore categorise only around 20% of livestock feed as being in competition with food for people: 14% as directly human-edible crops (mostly grains, plus some cassava, beans, rapeseed and soy oil), 3% as soybean cakes (also known as soymeal, which, although itself inedible, is classed by Mottet *et al.* as competing with human nutrition – see further discussion in the section "Quantity of food produced" below), and the remainder as grass and fodder from grassland that could be theoretically converted to cropland (not shown in the graph below because the proportions of pasture and fodder that are from grassland suitable for ***arable cropping*** are not clear – see Figure 3 above for the relative areas of grassland that are suitable and not suitable for arable cropping).

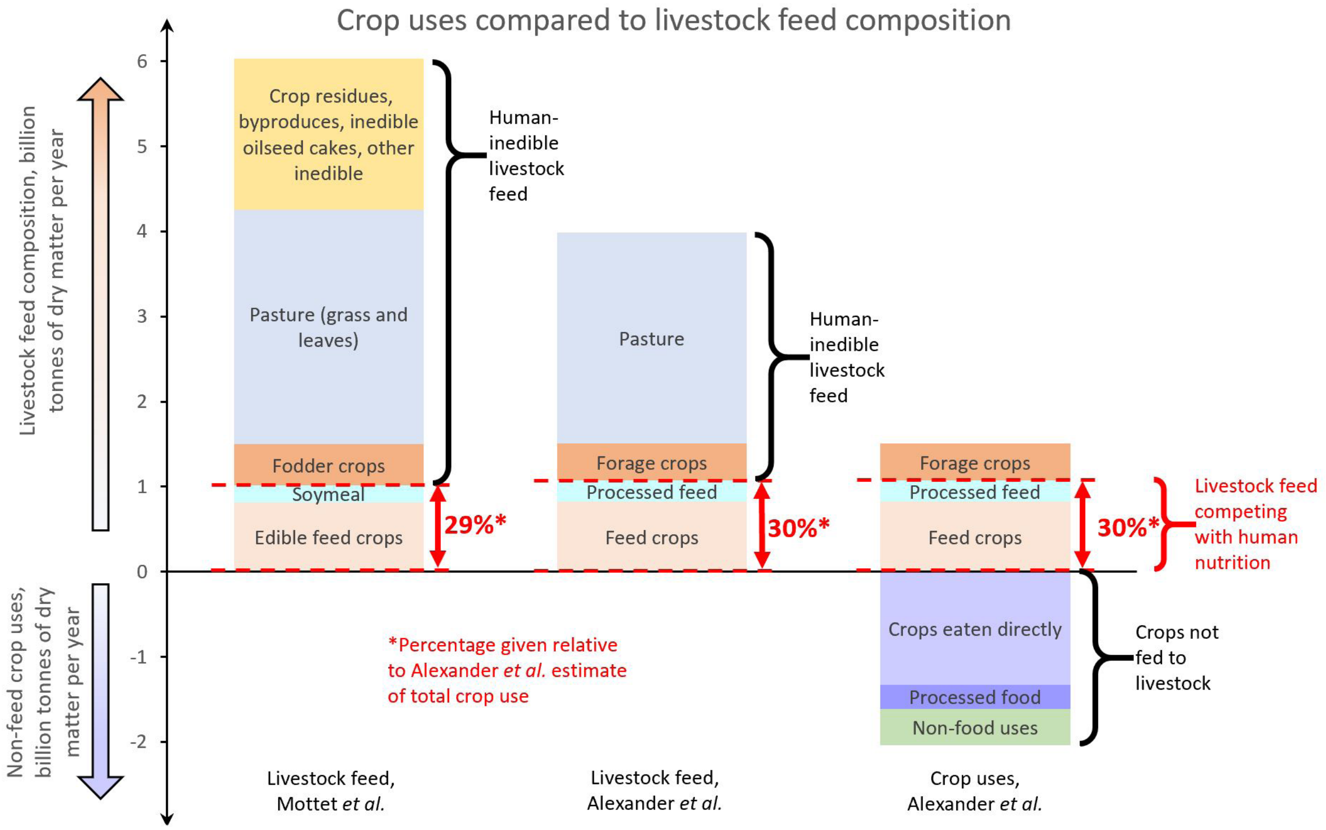

Figure 4: Crop uses compared to livestock feed composition. Crop use quantities are reported according to their end use for the year 2011 and do not include quantities for losses, stock variation or seed use. Forage crops are crops grown for animals to graze on (e.g. alfalfa); fodder crops can include grass grown for silage (fermented foliage that is fed to animals). Livestock feed estimates are for 2011 from Alexander *et al.* and for 2010 from Mottet *et al.* All quantities are reported on a dry mass basis. Red arrows indicate edible crops and soymeal. Data from Table 1 of Alexander *et al.*[7] and Figure 2 and Table SI 2 of Mottet et al.[5] Figure produced by the FCRN.

Fish

Feed-food competition can also apply to wild fish, which can be eaten directly by humans or fed to farmed fish or land-based livestock.

In 2010, 78% of wild-caught fish was consumed directly by humans, 18% was processed into fishmeal or fish oil (fishmeal and fish oil are generally produced at a ratio of five to one[8]), and 4% was used for other purposes (such as direct feeding to livestock, bait, or fertiliser)[9]. Fishmeal and fish oil are typically fed to farmed fish raised on ***aquaculture*** farms, but can also be consumed by people (as pharmaceuticals such as cod liver oil) or by land-based livestock[10], as shown in Figure 5[8].

More than 90% of the fish destined for non-food uses is in fact suitable for direct human consumption, being either prime food-grade (widely accepted as edible) or food-grade fish (accepted by some people as edible, depending on location and culture)[9].

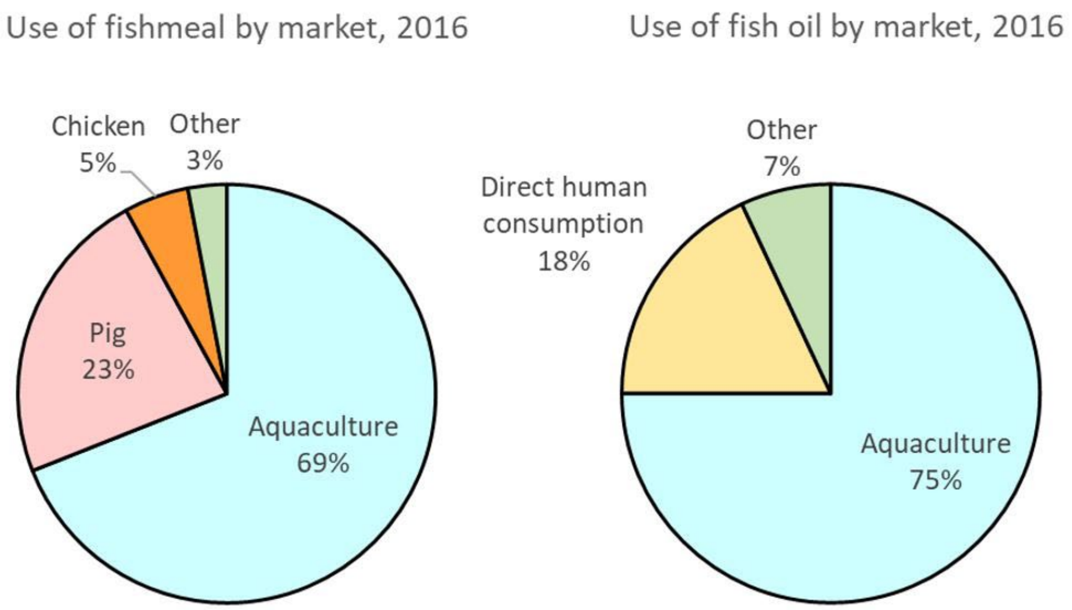

Figure 5: Use of fishmeal and fish oil by market, 2016. Figure produced by the FCRN; data from p60-61 of Bachis[8].

3. What are the differing narratives about feed-food competition?

This section explores how people frame and interpret the facts and figures around feed-food competition to argue for or against feeding edible food to livestock. Note that the narratives around feed-food competition are still developing and evolving, and thus do not always fall into clearly defined camps. As shown in Figure 6, these arguments touch on matters such as ***food security***, environmental sustainability, ***resilience*** and hypothetical alternative uses for feed crops. Each of these considerations plays a role in multi-dimensional debates about how the food system should produce food, what roles different livestock and crop production systems should play, and what we should eat. Such debates are driven by additional concerns such as health, economic inequality and animal welfare. This section also sets out an approach known as "livestock on leftovers", which some stakeholders have argued could minimise feed-food competition.

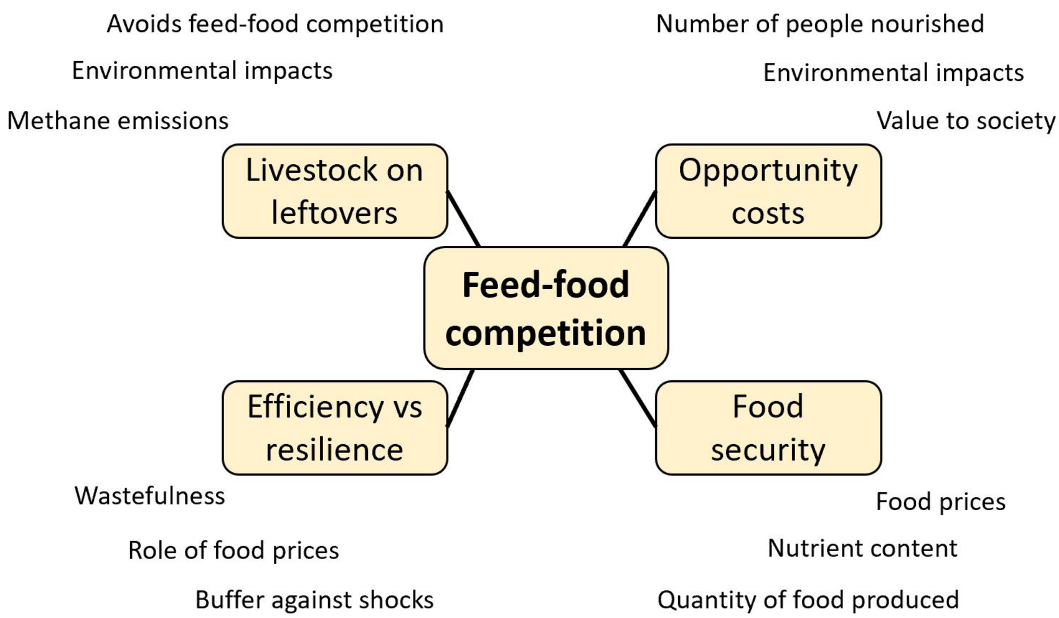

Figure 6: Some key issues related to the feed-food competition debate. Figure produced by the FCRN.

3.1 Opportunity costs

When choosing between feeding edible crops to livestock or to people, there are inevitably trade-offs in the number of people fed, the types of food produced, the impacts on the environment and so on. The issue of feed-food competition is therefore fundamentally linked to the idea of the opportunity cost. This concept, originally drawn from economics but now extended to other fields such as the environment, refers to the benefits forgone by choosing one of multiple, mutually exclusive courses of action[11]. As discussed below, the opportunity cost concept can be used in several ways to understand both feed-food competition and other related issues in the food system.

More people could be fed

The opportunity cost concept can be applied to the use of crops for both livestock feed and non-food purposes such as biofuels, tobacco and cotton. The argument is that more people could have been fed: edible crops could have been eaten directly[2], while land producing inedible crops could have produced edible crops[12] (for numbers, see the section "Quantity of food produced" below).

Many papers emphasise the competition between not only food and feed production but also biofuel production[2]. Commentators such as Fradj *et al.*[13] and Banerjee[14] stress the importance of the rapid growth in the quantities of crops used for biofuel and the resultant impacts on food prices[13,14].

Value to society of different types of food

Opportunity costs apply not only to the direct competition between using edible crops for feed, food or industrial uses such as fuel, but also to growing different edible crops, because each crop type has different ***yield*** levels, nutrient profiles and perceived value to society. The opportunity costs associated with feeding crops to livestock (or not) are therefore just one of many questions regarding what the food system should produce and for whom.

As an example of opportunity costs related to yield, typical yields in the UK are 8.3 tonnes/ha for wheat and 5.4 tonnes/ha for oats[15]. While both can be directly eaten by people, there is nevertheless a form of competition between using the land to grow wheat versus oats, in that different amounts of food will be produced. However, climate and soil quality will also limit what can be grown on a given piece of land.

Quantifying nutritional opportunity costs can be complex because of the many different health aspects of both individual food types and whole diets. One of the many possible ways of measuring nutritional value is to use ***nutrient profiling***[16]. Nutrient profiling models (i.e. algorithms for nutrient profiling, some of which are known as nutrient density indices) vary in detail, but generally consider levels of many different nutrients in a food, either alone or in conjunction with other measures such as the carbon footprint[17,18]. Most nutrient profiling models consider each item of food in isolation, but some account for the dietary context within which a food is eaten[19].

Some crops (such as coffee or wine-making grapes) may be perceived as luxuries in that they use land (and other resources) that could perform other roles that are arguably more important or socially beneficial, such as nature conservation or producing more nutritious food. For example, Vallianatos[20] argues that the production of cash crops (such as cocoa, sugar and peanuts) in Africa removes the best agricultural land from local food production, forcing people to cultivate marginal land for their own ***subsistence***; meanwhile, Wengraf[21] argues that colonialism in Africa encouraged cash crop production to the extent that food for local consumption had to be imported. (Note, however, that individual farmers may benefit from higher income from growing cash crops.) Some commercial crops – such as alcohol crops and sugar – can have harmful effects on health[22]. The perceived value of each type of crop relative to other options (e.g. is it better to produce beans or beer?) will differ between people according to their own preferences and values (shaped by wider social norms), such as the relative importance they place on health, enjoyment and ***livelihoods***.

Free market advocates might argue that these opportunity costs could be minimised through the mechanism of price, which can, in their view, automatically optimise the supply of each food type (healthy or otherwise) so that the most value to society is provided (as defined by people's individual purchasing choices). They might consider that government interventions via taxes, subsidies or regulations distort markets such that less value to society is provided than in an absolutely free market[23]. For example, Bowman[24] of the UK Adam Smith Institute argues that government dietary guidelines might reduce consumption of foods that make people happy.

An opposing viewpoint is that free markets do not in fact optimise production for maximum social wellbeing, for example because richer people, who can afford to spend more than poorer people, have more influence over what is produced. A free market could therefore prioritise producing luxuries for richer people over necessities for poorer people. Monbiot[25] argues that the "disproportionate purchasing power" of higher-income countries favours the production of grain-fed meat over grains for human consumption.

Furthermore, since the market price of a transaction rarely incorporates the full cost to society of rectifying any resulting damage (such as pollution), exchanges that happen spontaneously in a free market (because they benefit both buyer and seller) might nevertheless decrease overall social wellbeing[26]. These costs to society are known as negative ***externalities*** (positive externalities also exist, where a transaction has a beneficial effect on wider society). If the cost of rectifying any damage done by a transaction is incorporated into that transaction's price, the externalities are said to be ***internalised***[27].

Another criticism of free market principles is that they assume people make rational transactions that improve their wellbeing – but, in reality, people can make apparently irrational purchasing decisions because of imperfect information, cognitive biases, addiction or peer pressure[28]. Thus, free markets might not allocate resources in a way that achieves maximum social wellbeing.

In practice, markets are not truly free because of factors including the aforementioned lack of perfect information available to both buyers and sellers, government policies, and social and political power structures.

Environmental impacts could be lower

Opportunity costs can describe both *outputs* of the food system, such as food nutrients or number of people nourished (as described above), and *impacts* of the food system, such as biodiversity loss or climate change.

In the latter framing, an opportunity cost of producing a given amount of crop-fed livestock products is that the same amount of human-edible food could have been produced with lower environmental impacts. For example, Di Paola *et al.* find that producing plant protein uses 2.4–33 times less land and water and produces 2.4–240 times fewer greenhouse gas emissions than animal protein from livestock fed on crops[29]. From this viewpoint, feeding crops to livestock is environmentally inefficient and it would be preferable for people to eat plant-based foods instead of crop-fed animal products.

People who strongly prefer to consume animal protein might argue that these higher environmental impacts are a worthwhile trade-off for producing a food type they think is better tasting or more nutritious than plant-based foods.

Other impacts that could theoretically be reduced if edible crops were fed to people rather than to livestock are habitat destruction and carbon emissions caused by the expansion of cropped farmland into natural ecosystems such as forest or grassland. For example, the carbon footprint for poultry (typically fed a diet high in human-edible feed and thus contributing to feed-food competition[5]) is usually reported as 3.7 kg CO_2/kg of carcass weight. In a contrasting approach, however, Searchinger *et al.*[30] estimate there is an additional "carbon opportunity cost" of 11.5 kg CO_2/kg of carcass weight, on the grounds that 11.5 kg CO_2 could be sequestered if the land used to produce the poultry and its feed were instead used to restore forests.

In reality, feeding less human-edible food to animals might not reduce environmental impacts, because people might choose to eat animal products from grazing systems rather than switching to plant-based foods. Grazing systems generate their own biodiversity and carbon impacts. Blaustein-Rejto *et al.*[31] argue that feeding edible crops to livestock is therefore beneficial because it frees up more land for (say) rewilding than if the same amount of animal products were produced via grazing. For more details, see What is the land sparing-sharing continuum?

Critiquing the anti-grazing view, proponents of regenerative grazing practices might argue that it is preferable to consume animal products from systems that, in their view, maximise ***carbon sequestration***, biodiversity and soil health, in preference to plant-based foods from conventional intensive cropping systems, which face issues such as fertiliser runoff and soil erosion[1]. However, organisations such as the Vegan Organic Network suggest that livestock are not a necessary feature of regenerative farming.

3.2 Food security

One concern around the issue of feed-food competition is its effect on food security, particularly in relation to the quantity of human-edible food that is produced, its nutritional content, and the price of different food types.

Quantity of food produced

An animal necessarily produces fewer calories (as animal products) than were present in its feed, since a portion of the feed energy is metabolised by the animal, is bound up in inedible body parts, or lost as faeces and urine. For example, feedlot ***ruminant*** systems consume over four times the amount of human-edible protein that they produce[5]. One interpretation of these figures is that feeding edible crops to livestock undermines food security because more food could theoretically be available to humans if the crops were instead eaten directly by people (see for example Monbiot[32] and Erb *et al.*[33]).

In one alternative scenario, Cassidy *et al.* estimate that if all edible crops were consumed directly by humans instead of some being consumed by livestock, global availability of food calories would increase by 70% – enough to feed another 4 billion people – and protein availability would double[34]. This estimate does not account for the potential increase in crop output that might arise from using the 0.7 billion ha of grassland that, although currently grazed, are capable of being cropped[5] (note, as discussed above, that converting grassland to cropland would have implications for both carbon emissions and biodiversity).

Other alternative scenarios consider not just the quantity of crops fed to livestock, but also which types of livestock are raised, because each animal species has a different ***Feed Conversion Ratio*** and requires a different feed composition to thrive. For example, redirecting feed from grain-fed beef production to pork and chicken production (in equal quantities) could increase global calorie availability by 6% (enough to feed another 357 million people). Similarly, redirecting feed from all meat production to feed-based egg and dairy production would increase global calorie availability by 14% (enough to feed another 815 million people)[34].

Another viewpoint, however, is that feeding *some* human-edible crops to livestock can "leverage" the consumption of human-inedible feed such as grass and thereby make a net positive contribution to the availability of food for humans.

In one example of this leveraging argument, Mottet *et al.* show that some specific types of livestock system that incorporate small amounts of human-edible feed (including some soymeal) are able to make net additions to the supply of human-edible protein (see for example grazing cattle in non-OECD countries and backyard poultry in OECD countries in Table 1 of Mottet *et al.*[5]).

At the global level, however, ruminants produce 1 kg of human-edible protein (as meat and dairy) by consuming 0.6 kg of human-edible protein (such as grains, pulses and roots), 0.4 kg of soymeal and 1.0 kg of human-inedible protein (such as grass).

Whether or not ruminants add to the net global supply of human-edible protein thus depends on whether soymeal is classed as edible or inedible. Mottet *et al.* themselves classify soymeal as inedible to humans (although soybeans are edible), but also as competing with human nutrition. This is because the production of soybeans is primarily driven by demand for soymeal: the majority of the economic value of a soybean crop comes from the soymeal component, not the oil component (see Figure 1 of Mottet *et al.* for more information). Over 99% of soymeal is used as animal feed[35].

In another example, Van Zanten *et al.* conclude that dairy cows fed a mixture of human-edible and human-inedible feed, such as grass from marginal lands, are able to produce more human-edible protein than they consume[36].

Note that the categories human-edible and human-inedible are not necessarily clear-cut. Rather, they depend on both cultural norms as to what crops can be eaten by humans (which can change) and the quality of the crops in question.

For further discussion of the efficiency (or otherwise) of livestock production including the idea of "leveraging", see What is environmental efficiency? And is it sustainable? and the FCRN report Lean, green, mean, obscene…? What is efficiency? And is it sustainable?

Nutrient content

When considering food security, the nutrient profile of food is important as well as the total quantity of food available for human consumption, particularly given growing concerns around the (often co-existing) problems of ***micronutrient deficiencies*** and obesity (read more in the FCRN's building block What is malnutrition?). Animal products, it is argued, are dense in essential ***micro*** and ***macro nutrients***, sometimes in forms that are more easily utilised by the human body (i.e. more ***bioavailable***) than those found in plant-based foods[37], and can therefore contribute to food security, particularly in areas where it is hard for people to obtain adequate nutrition from plant-source foods[5,38]. The nutritional properties of animal products are also used to support pro-livestock advocacy (see the Egg Nutrition Council[39] and Capper *et al.*[38]) in high-income countries with lower risk of food insecurity (although in the case of the paleo diet, proponents[40,41] tend to recommend grass-fed over grain-fed meat for health reasons).

In contrast, Berners-Lee *et al.* argue that generally there is "no nutritional case for feeding human-edible crops to animals" because doing so decreases the net supply of calories, protein, zinc and iron. However, Berners-Lee *et al.* found that feeding human-edible crops to animals in fact increases supplies of one of the nutrients they analysed: vitamin A[42]. Berners-Lee *et al.* also note that meat and dairy may be nutritionally important to people who do not have access to a diversity of other food types.

Food prices

Another framing of the impacts of feed-food competition considers the interaction between food prices and food security. According to this perspective, crops are allocated towards feed or food according to changing demand patterns (such as higher meat demand linked to rising incomes[14]), which in turn influence food prices and therefore the ability of some people to afford the food that they need or want.

For example, using edible crops for non-food purposes, such as animal feed, could undermine food security by increasing demand for those crops and thus increasing their price. This would particularly affect poorer people who may rely more heavily on plant staples such as grains (which are a food type in competition with livestock feed-production)[43]. A similar concern applies to feeding wild fish to farmed fish: people who rely on low-value fish species might not be able to afford those species if fishmeal producers can pay a higher price for them[44].

In a relevant example, Aguiar and Nunes Da Costa claim that Brazil produces enough food for both domestic consumption and export, despite competition between food, feed and biofuel production, because the overall supply of food is sufficient for all three types of demand. The paper estimates that, in 2013, Brazil actually produced 112% of the calories necessary to feed all Brazilians. Had no animal foods been produced, crop production would have covered 574% of Brazilian calorie demands; with neither animal food nor biofuel production, 682% of calorie demands would be met. Despite a sufficient supply, many Brazilians are still unable to afford enough nutritious food, showing that the *quantity* of food supply alone does not determine whether people are food secure. The paper does not estimate whether food prices would be lower – and thus whether nutritious diets would be more affordable – if neither animal foods nor biofuels were produced[45].

In contrast, Steinfeld and Opio[43] argue that feeding grains to livestock is only made possible in the first place by a surplus of cheap grains created by improvements in crop productivity. Indeed, Manceron *et al.* find that feed-food competition has *decreased* over the last few decades, in that the share of cropland used for feed production has decreased from roughly 45%-50% in the 1970s to 35%-39% in 2009, partly due to increased crop productivity and greater use of by-products such as oilseed (e.g. soy) cakes[12]. (The range of values indicates different allocation methods for by-products.) The absolute area of cropland producing feed has remained roughly static over the same time period, while the productivity (quantity of feed crops divided by land area used to grow them) has tripled between 1961 and 2009.

Furthermore, the argument that feeding edible crops to animals reduces the amount of food available to humans assumes that those crops would still be grown in the absence of market demand for animal feed and thus would be available for people to eat. This is not necessarily true: reduced demand for animal feed might lead to lower production of those crops, particularly for crops such as soy, whose production is driven primarily by feed-demand[5].

3.3 Efficiency versus resilience

While feeding edible crops to livestock may not be "efficient" in terms of the number of people nourished per hectare or per unit of environmental impact compared to eating crops directly, commentators including Steinfeld and Opio[43] argue that this lack of efficiency is not necessarily a problem. This line of thinking suggests that the grain-fed livestock sector can "cushion" the food system against economic or ecological shocks and increase its resilience, e.g. by releasing grain for direct consumption during the 2008 economic crisis[37]. This effect could be mediated by an increase in feed crop prices in the event of a shortage, which would cause higher meat prices and a consequent fall in meat consumption[14]. Fairlie notes that a similar cushioning role could be played by other non-food uses for grains, such as production of alcohol or biofuels, which maintain crop production above the minimum level necessary for feeding people[46]. See also the section "Food waste as a buffer against food insecurity" of What is food loss and food waste?

Proponents of regenerative or ***agroecological*** systems for producing crops or livestock might argue that both "sides" of the feed-food competition debate – i.e. advocates for feeding crops either to livestock or directly to people– ignore the vulnerabilities of intensive crop systems, such as their reliance on fossil fuels and exposure to pests and diseases, regardless of whether livestock or people eat those crops. According to this view, reducing feed-food competition through avoiding crop-fed livestock production would not completely eliminate the perceived harmful effects of intensive cropping systems[47,48].

Conversely, it could be argued that increasing crop yields (e.g. through sustainable intensification) could in fact improve the resilience of the food system by creating more ***biomass*** for all end-uses and reducing the need for the expansion of agricultural land, thus reduce pressures caused by feed-food competition[2].

3.4 Livestock on leftovers

In response to the perceived problems of feed-food competition, some researchers have suggested an approach to food production that minimises feed-food competition without eliminating animal agriculture altogether. Under this approach, inspired by traditional uses of livestock as recyclers of food waste and sometimes known as "livestock on leftovers", livestock would eat only human-inedible feedstuffs such as grass, food waste, waste biomass from biofuel production and other industrial by-products – thus recycling otherwise inedible biomass streams into the food system[2,49–51].

"Livestock on leftovers" could produce at least 9 g of animal protein per person per day (excluding fish[51]), and up to 31 g if leftovers are allocated across different types of livestock system to maximise protein production (based on leftovers available in the European Union from current food waste levels and grass resources[52]). This is not enough to meet the projected global increase in demand for animal products but, according to proponents of this perspective, enough to make a useful contribution to overall protein requirements1. "Livestock on leftovers" could even encompass edible insect production, since insects can consume food waste[53]. Yet another approach to reducing the land area devoted to animal feed, still in the speculative stage, would be to feed livestock on protein from industrially-fermented microbes such as algae[54].

As shown in the figure below, Van Zanten *et al.*[55] review several studies (assessed on a global scale) and find that a "livestock on leftovers" approach could use one quarter less arable land, globally, than a purely vegan diet. That said, a purely vegan diet would use less arable land overall than today's average global diet. If consumption of animal products were to exceed the amount that could be provided by "livestock on leftovers", then feed-food competition would be likely because any additional feed crops must be produced using arable land; alternatively, wild land might be converted to pasture.

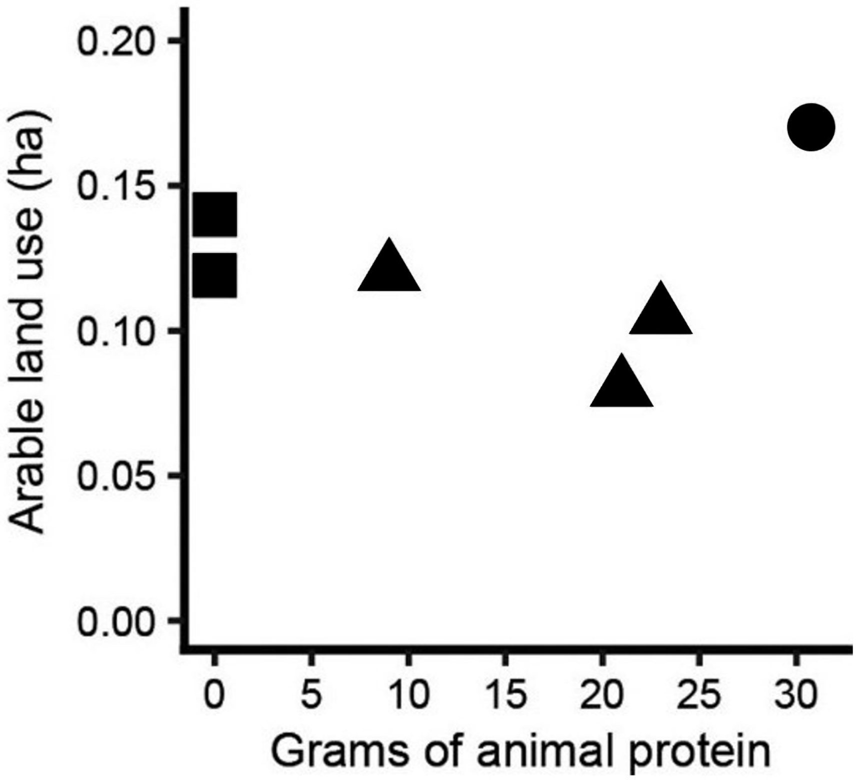

Figure 7: Relationship between animal protein consumption and arable land use, based on several studies. Squares = vegan diet. Triangles = livestock on leftovers. Circle = current diet. Source: Van Zanten et al.[55]. Figure reproduced and modified by the FCRN under the Creative Commons Attribution 4.0 International licence.

Note that a "livestock on leftovers" scenario would still use large amounts of pasture land, which presents an opportunity cost in that this use limits the potential for conserving certain ecosystems (such as woodlands or natural grasslands) and sequestering carbon through rewilding or planting trees (as suggested by Harwatt and Hayek[56]). Indeed, much deforestation is driven by the creation of pasture for ruminants[1,31,57]. In some specific cases, however, certain grazing management practices could lead to limited sequestration of carbon, so the "livestock on leftovers" scenario could support some degree of carbon sequestration[1].

According to Schader *et al.*, "livestock on leftovers" could reduce agricultural greenhouse gas emissions by 18% in 2050 relative to business as usual or by 5% relative to current emissions, because of reduced animal numbers and area of cropland cultivated. "Livestock on leftovers" could also decrease other environmental impacts including soil erosion and pesticide use (see the figure below)[51].

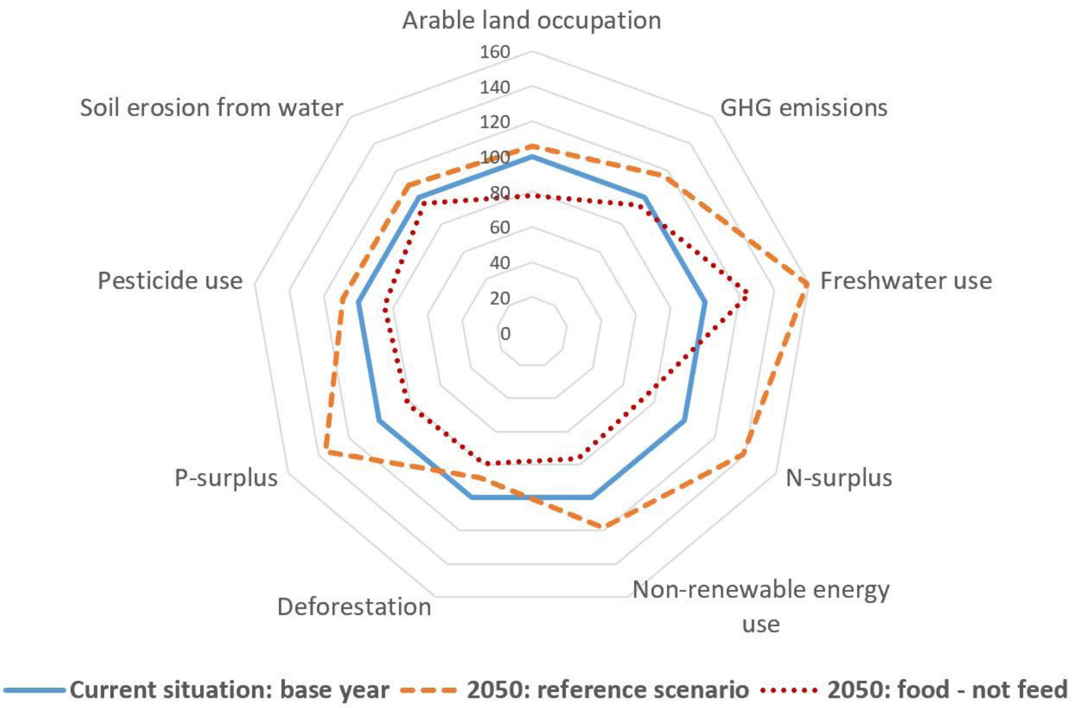

Figure 8: Environmental impacts of a "livestock on leftovers" (i.e. "food – not feed") scenario in 2050, relative to business as usual (2050 reference scenario) and the current situation. Impacts are shown as a percentage of current impacts. Figure produced by the FCRN; data from Schader et al.[51].

Röös *et al.* find that, while "livestock on leftovers" would reduce greenhouse gas emissions relative to business as usual (by around 40%), a purely vegan scenario would reduce emissions still further (by 73% relative to business as usual), by avoiding methane and other emissions from livestock[49]. This underlines the point that judgements about the role of livestock in the food system may need to consider multiple aspects, not just the extent to which livestock feed competes with food production.

4. Conclusion

The term feed-food competition, although often narrowly construed as referring only to the conflict between feeding edible crops to people or to livestock, can serve as a starting point to discuss wider issues of inequality, sustainability and unintended consequences in relation to the distribution of resources within the food system and economy.

People construct different narratives about the competition between feed and food production. According to some viewpoints, using farmland or edible crops for purposes other than feeding people directly is a problem, because doing so decreases the number of people that can be fed and can produce higher environmental impacts than eating crops directly. At the opposite end of the spectrum of arguments, others argue that feeding edible crops to livestock is not a cause for concern, because this system makes use of plentiful grain and has benefits such as contributing to resilience, using less land than grazing systems do, and providing nutrient-dense foods that many people like to eat.

In an attempt to solve some of the perceived problems of feed-food competition, proponents of the "livestock on leftovers" approach suggest that livestock could still have a place in the food system, albeit in a different role to today and with lower production of animal protein than is expected with current trends.

These differing perspectives from which people view feed-food competition, including more nuanced standpoints that may fall somewhere between the main positions outlined in this piece, illuminate the wider conversation happening between consumers, farmers, industry, NGOs and policymakers about how food should be produced, what we should eat, whether consuming animal products is beneficial, and, if so, how livestock should be reared.

Recommended resources

To learn more about feed-food competition, we recommend the following resources:

- Journal article (open access): Muscat, A., de Olde, E. M., de Boer, I. J. M. & Ripoll-Bosch, R. The battle for biomass: A systematic review of food-feed-fuel competition. Global Food Security (2019). doi:10.1016/j.gfs.2019.100330
- Journal article (open access): Mottet, A. *et al.* Livestock: On our plates or eating at our table? A new analysis of the feed/food debate. Global Food Security (2017). doi:10.1016/j.gfs.2017.01.001
- Journal article (open access): Alexander, P. *et al.* Losses, inefficiencies and waste in the global food system. Agric. Syst. (2017). doi:10.1016/j.agsy.2017.01.014
- Journal article (open access): Schader, C. *et al.* Impacts of feeding less food-competing feedstuffs to livestock on global food system sustainability. J. R. Soc. Interface (2015). doi:10.1098/rsif.2015.0891
- Journal article (open access): Van Zanten, H. H. E. *et al.* Defining a land boundary for sustainable livestock consumption. Global Change Biology (2018). doi:10.1111/gcb.14321

Glossary

Agricultural yield
Agricultural yield is the average net output of agricultural product (e.g. in kCal, grams protein, or net profit) per unit of farmland per year. The total amount of farmland includes all land that is required to generate the output (e.g. also land that is used to grow feeds or to produce manure).

Agroecology
Agroecology can be defined as a range of agricultural practices that are based on applying ecological concepts and principles to optimize interactions between plants, animals, humans, and the environment. Agroecology also places strong emphasis on the social and ethical aspects of food production. Its advocates tend to have a preference for organic practices (e.g. the avoidance of mineral fertilisers and chemical inputs, and instead prefer the use of biofertilisers, natural pesticides and crop rotation), it also emphasises the need for a 'multifunctional' farm system to produce both food and non-food outputs, and for smallholder and indigenous, as opposed to large scale farming. Agroecology has been interpreted in different ways: it also refers to a social movement and field of science.

Aquaculture
Aquaculture refers to the breeding, rearing and harvesting of animals and plants in aquatic environments.

Arable crops and arable land
Arable crops are those such as wheat and barley, which require good soil quality and a favourable climate to grow, and land amenable to the use of ploughing and harvesting machinery. Arable land is by definition land used to grow arable crops, in contrast to land used for fruit and vegetable crops and for pasture used to feed grazing animals.

Bioavailability
Bioavailability is the extent to which nutrients that are ingested can be utilised by the body.

Biodiversity
Biodiversity refers in the broadest sense to the variety and variability of living organisms in a particular area, or on earth in general. More specifically, the concept is used to denote different aspects of the variety and variability of life, e.g. the number of species in an area (species richness) or the size of species' populations (species abundance). Biodiversity is measured in different ways and at various scales from the genetic through to the landscape level.

Biomass
Biomass refers to dry weight of plant-based material that has been harvested or is available on an area of land. Typically, it refers to the use of plants not for food or fibre, but rather for (bio)energy.

Carbon sequestration
Carbon sequestration is any process by which carbon dioxide is removed from the atmosphere and stored elsewhere, whether by biological or technological means. There are two main types of carbon sequestration, terrestrial (carbon plants and soils), and geologic (carbon stored in rock formations). One classic example of carbon sequestration is reforestation.

Ecosystem services
The tangible and intangible benefits that are provided by ecosystems to humans, which both enable human life and that contribute to its quality. Ecosystem services include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth.

Externality
An externality is an economic cost or benefit incurred or received by a third party to a transaction (i.e. by an individual or group that is not the buyer or seller), such as the cost of cleaning up pollution. Negative externalities refer to an overall cost to society, while positive externalities refer to an overall benefit to society. The cost of externalities can be ***internalised***.

Feed conversion ratio
The feed conversion ratio is a ratio measuring the efficiency with which farmed animals convert animal feed into the desired output (e.g. meat, milk, eggs, and so forth). The ratio is calculated by dividing the mass of feed inputs (e.g. grass, soymeal, cereals, etc.) by the mass (or food energy value) of outputs. A related concept is feed efficiency (the inverse of the feed conversion ratio).

Food security
Food security is an idealised state or goal where all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life.

Internalised cost
Cost internalisation is the incorporation of the cost of an ***externality*** into the cost of an economic transaction, such as through a tax to cover the costs of rectifying pollution.

IPCC
The Intergovernmental Panel on Climate Change (IPCC) is the international body for assessing the

science related to climate change. It is administered by the United Nations with participation and decision making from 195 member states. The assessments that it produces provide the basis for government at all levels to create climate related policies.

Land use
Land use is the purpose for which an area of land is used by humans: e.g. cropland, urban settlements, managed forests. Wild land, by contrast, is that not used by humans.

Livelihood
A livelihood is a person's, household's, or group of people's means of making a living. It encompasses people's capabilities, assets, income, and activities that are required for securing the necessities of life, such as food, water, medicine, shelter and clothing.

Macronutrients
Macronutrients are fats, proteins and carbohydrates (starch, fibre, sugar) that are needed for a wide range of bodily functions and processes.

Micronutrient deficiencies
Micronutrient deficiencies result from a diet lacking the essential vitamins and minerals that humans require in small amounts for proper growth, development, and bodily functioning. These include iodine, calcium, iron, zinc, and vitamins A, B, and C, among others. Micronutrient deficiencies are the cause of a range of diseases affecting physical and mental development, and can increase susceptibility to infectious diseases.

Micronutrients
Micronutrients are minerals (e.g. iron) and organic compounds (e.g. vitamin A) found in food, which the body requires in very small amounts to produce substances such as enzymes and hormones. They are essential for proper growth, development and bodily functioning. Essential micronutrients are those that cannot be synthesised by the body and so must be obtained through diet.

Nutrient profiling
Nutrient profiling is the classifying or ranking of foods according to their nutritional composition for reasons related to preventing disease and promoting health. Algorithms for this process are known as nutrient profile models.

Opportunity cost
Opportunity cost is an economic concept referring to the benefits forgone by choosing one of multiple, mutually exclusive courses of action.

Resilience
In the context of food system sustainability, the concept of resilience refers to the ability of the food system to cope with and recover from socio-economic or environmental shocks and pressures. A resilient system has a certain degree of toughness and is able to bounce back against or adapt to disturbances. A resilient food system, for example, is able to keep providing food or other outputs such as livelihoods for farmers, drinking water, and biodiversity conservation under conditions of drought, a drop in food prices, war, climate change, the spread of virus in plants or animals, and so on. Resilience can be thought of at different scale levels. For example, what may be considered as resilient on a national level may not be understood to be resilient at a farm level. While some see resilience as synchronous with sustainability, others point out that a resilient system may also be one that resists needed transformation; an unsustainable status quo may in fact be resilient to change.

Rewilding
Rewilding refers to the intentional restoration of natural ecosystems, sometimes supported by the reintroduction of particular native species (particularly predators such as wolves) to areas where they are no longer present.

Ruminant
A ruminant is a mammal with a four-compartmented stomach which enables it to acquire nutrients from plant-based food such as grasses, husks and stalks. Examples of ruminants include cattle, sheep, goats, deer, giraffes and camels. After swallowing, microbes in the ruminant's rumen (its first stomach compartment) begin fermenting the food. This process generates fatty acids (nutrients which the ruminant absorbs through its rumen walls) and methane, which the ruminant eructs or burps. Through this process, ruminants are able to digest coarse cellulosic material which monogastrics and people cannot. Methane emissions from ruminants are a significant source of greenhouse gasses from ruminant-based livestock systems.

Subsistence farming
Subsistence farming refers to rearing animals and growing crops only for your own consumption, without having any surplus to take to market as a source of cash income.

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