Lean, green, mean, obscene…?
What is efficiency? And is it sustainable?

Animal production and consumption reconsidered.

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1. Introduction

"Food systems need to become more efficient. We need to produce food in ways that use fewer resources and generate fewer negative environmental impacts. This drive towards efficiency is essential if we are to achieve more sustainable food systems."

Such is the typical conclusion of numerous policy documents and industry statements, based on academic papers published in agricultural science and life cycle assessment journals.

It is a well-rehearsed observation that the food system today is undermining the environment upon which future food production depends. We know too that given current trends, our problems are set to grow, not just because our population is growing, meaning more mouths to feed, but also because our food demands are changing. As people on average become richer, they demand and can afford not just more food, but more of the foods that they like, notably those of animal origin. The rearing of animals for flesh, eggs and milk generates some 14.5% of total global GHG emissions, occupies 70% of agricultural land and is the main cause of the environmental problems such as biodiversity loss and water pollution.[1,2] Moving from land to water, there are major concerns about the depletion of wild fish stocks and the negative effects of over fishing on aquatic ecosystems. Aquaculture production bridges and is linked to concerns in both the terrestrial and aquatic domains: it is a user of land based resources, but its production has been underpinned in recent years on wild fish stocks used as feed inputs.

While there is general agreement that action is needed to address the environmental problems caused by the food system, what such 'action' should be is the subject of substantial attention and debate within the policy, academic, business and NGO communities. One word that comes up time and again in discussions about the way forward is '*efficiency*.'

But what is efficiency? What are we being efficient *with* and efficient *for*?

While environmental efficiency is an often stated policy and business goal, for others the concept is problematic and the assumed link with environmental sustainability contested. There are different views about what efficiency means, what it should be applied to, its relationship with a range of environmental goals, and whether, as a concept, it adequately encapsulates the multiple objectives we may have for the food

1 Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A. & Tempio, G. (2013). Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome.

2 FAO (2006) Livestock's Long Shadow. Rome: Food and Agriculture Organisation, Rome

system. Indeed, the way stakeholders use, critique or reinterpret the term reveals much about what people ultimately want.

This paper seeks to shed light on the various meanings that environmental efficiency holds for different stakeholders, by exploring their use and understanding of the word in relation to terrestrial and aquatic livestock production (TAL). It begins by defining the concept in its narrowest sense before moving on to discussing mainstream uses, criticisms and counter uses (Section 2). It then (Section 3) considers how these different takes on the term manifest themselves in discussions about efficiency in relation to the inputs to the system, the negative impacts arising, and the desired outputs. It concludes (Section 4) with an attempt to distil some of the key concerns, implicit as well as explicit, that people have about the word before suggesting a new complementary (rather than replacement) concept, that may add focus to future discussions.

2. What is efficiency? A definition and some critical perspectives

2.1. Efficiency: classical usages

Efficiency, classically defined, is a ratio. The Oxford English Dictionary provides the following definition:

> *"The ratio of the useful work performed by a machine or in a process to the total energy expended or heat taken in."*

Efficiency is therefore relative: it expresses the relationship between inputs and outputs.

The word is used in many different technical and commercial contexts, including the agricultural domain, as a way of viewing the relationship between inputs (such as labour, time, capital) to outputs. Inputs in the agricultural sector may include land, nutrients (nitrogen, phosphorus), agrochemicals, water, energy, labour or capital. The output is considered in mainstream usages to be food (or fibre or bioenergy – not discussed here), usually expressed in terms of mass, monetary value, caloric energy or protein.

A very common way of expressing efficiency in the animal production sector is the feed conversion ratio – the mass of feed inputs in relation to the mass (or food energy value) of outputs – meat, milk and so forth (Table 1). Variants may include protein conversion ratios (mass of feed protein: food protein) which calls for caution when comparing numbers from different studies, all the more so when output is expressed in different terms e.g. live animals, carcass weight or edible meat.

Table 1: Feed conversion rations for a selection of animals and animal products

	Beef	Pig	Poultry	Dairy	Egg	Fish	Insects
Godfray *et al* 2010[3] – feed required to produce 1 kg of meat, kg of cereal per animal	8	4	1				
Galloway *et al* 2007[4] – total global feed to meat	20	3.8 (non-rum)	3.8 (non-rum)				
Galloway *et al* 2007[5] – feed from arable land to meat	3	3.4 (non-rum)	3.4 (non-rum)				
Wilkinson, 2011[6] – kg feed (dry-matter) per kg meat	7.8–27.5	3.6	2.0	1.1	2.2		
Pelletier *et al*, 2009[7] – amount of feed used to raise 1 kg of salmon						1.1–1.5	
van Huis *et al*, 2013[8]							0.9–1.7

2.2. Environmental efficiency: uses, counter-uses, criticisms

With the evolution of environmental life cycle thinking and its application to food, the idea of *environmental* efficiency was born. Using this expanded concept, the efficiency of a system is now to be viewed not just in terms of how much useful output (meat, milk and so forth) it produces in relation to the inputs but in relationship to its undesirable outputs, such as GHG emissions, soil and water pollution.

3 Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Toulmin, C. (2010). Food Security: The Challenge of Feeding 9 Billion People. *Science*, 327(5967), 812-818. doi: 10.1126/science.1185383

4 Galloway, J. N., Burke, M., Bradford, G. E., Naylor, R., Falcon, W., Chapagain, A. K., Smil, V. (2007). International Trade in Meat: The Tip of the Pork Chop. AMBIO: *A Journal of the Human Environment,* 36(8), 622-629. doi: 10.1579/0044-7447(2007)36[622:ITIMTT]2.0.CO;2

5 *Ibid*.

6 Wilkinson, J.M.,(2011), Re-defining efficiency of feed use by livestock. *Animal* 5:7, pp 1014–1022, doi:10.1017/S175173111100005X

7 Pelletier, N., Tyedmers, P., Sonesson, U., Scholz, A., Ziegler, F., Flysjo, A., Silverman, H. (2009). Not All Salmon Are Created Equal: Life Cycle Assessment (LCA) of Global Salmon Farming Systems. *Environmental Science & Technology*, 43(23), 8730-8736. doi: 10.1021/es9010114

8 van Huis, A. (2013). Potential of Insects as Food and Feed in Assuring Food Security. *Annual Review of Entomology*, 58(1), 563-583. doi: 10.1146/annurev-ento-120811-153704

Both inputs and outputs can generate negative impacts. Inputs can cause harm because of the way they are extracted or produced (nitrogen fertiliser), because they reduce availability for other uses (water) or because they cause damaging wastes. The production of outputs can have impacts that are mediated by, but also independent of, the inputs that are used (e.g. GHG emissions in the case of ruminants).

Thus, actions to improve environmental efficiency are geared at producing more output and less negative impact per unit of input. Environmental efficiency is thus a measure not just of the desired *outputs* relative to *inputs* but also of the desired *outputs* relative to undesired outputs or *impacts*.

The relationships among all these are influenced by 'practical' factors such as technology and management and geographic and climatic conditions – but also by the desires that drive the food system and our ultimate goals as a society – that is, what is wanted from and for the system.

The mainstream view, generally advanced by policy makers, the food industry and many academics drawn from agricultural sciences, argue strongly for more 'efficient' animal production systems on the grounds that global consumption of animal products is growing rapidly. Such growth is not only inevitable but also positive in so far as it drives economic growth and wider availability of nutrient-rich animal source foods among low-income nutritionally deprived communities. The sector's major environmental impact is to be addressed by improving breeding, feeding, nutrient, housing and land management systems so as to achieve greater outputs of food for a given level of inputs. Technological innovations in the areas of genetics and precision farming (for instance) have a strong role to play. This 'more for less' take on efficiency is sometimes known as 'sustainable intensification' (SI) although some argue that SI can and should be more richly defined.[9]

A second approach, often held by environmental and animal welfare non-governmental organisations, as well as a growing number of academics generally from northern and western Europe, argues that while it may be necessary to produce food in ways that generate fewer environmental impacts per unit of product, production side measures alone will not sufficiently reduce emissions, or address other environmental concerns. We need to change the ultimate driver of inefficient production – our demand for animal products. Plant based diets are more 'efficient;' they deliver more food energy value and protein per unit of environmental impact than those rich in meat. Some stakeholders go further; they argue that diets rich in animal products contribute to chronic diseases and that a shift to more plant based diets will benefit our health (an argument that is refuted by others and discussed further in 3.3.a *Food and nutrition* below). Diets high in animal products are also associated with overweight and obesity – in short, to overconsumption – which together with its twin, food waste, represents the ultimate inefficiency.

A third approach also found among those in the environment movement as well as the international development community (and overlapping with the second perspective) argues that the main problem with 'efficiency' is that it is simplistic and reductive. The

[9] Garnett T, Appleby M C, Balmford A, Bateman I J, Benton T G, Bloomer P, Burlingame B, Dawkins M, Dolan L, Fraser D, Herrero M, Hoffman I, Smith P, Thornton P K, Toulmin C, Vermeulen S J and Godfray H C J (2013). Sustainable Intensification in Agriculture: Premises and Policies, *Science,* 34, 6141, 33-34

concept fails to encompass differences in the *qualities* of resources used as inputs, the types and multiplicity of outputs generated and their irreducible interconnectedness. This perspective brings in not only difficult questions about the need for more holistic perspectives (and what that means) but also socio-ethical dimensions of food provisioning. These include people's livelihoods and their relationship with land and water, and our treatment of the animals we rear.

3. Efficiency: inputs, impacts and outputs

These different takes on efficiency colour and are coloured by differing views about the desirability of the various *inputs* to TAL production; differing values assigned to the *outputs* (reflecting differing priorities); and differences in the weight given to particular environmental *impacts*, as well as to any trade-offs that arise between the quantity or quality of outputs and impacts. Ultimately, stakeholders may reject the whole idea of measuring progress towards sustainability in relative rather than absolute terms – which is what efficiency does. This section explores these disagreements by taking a closer look at each of the terms of the ratio: inputs, impacts, and outputs.

3.1. Efficiency in relation to inputs

What are the inputs to the production system? This subsection looks at just three very commonly recognised ones; feed, land and water, in some detail (3.1a, b and c). But it also highlights (3.1.d.) that there are many other inputs to the system as well. These may not be classed as such by different stakeholders because they are taken for granted; alternatively, their use, or the legitimacy of their use may be contested. Additionally we have chosen to discuss an input such as nitrogen in relation to the impacts they generate (3.2), a decision that shows how blurred are the boundaries between categories. In other words, the first term of the efficiency ratio may not be as simple as at first appears.

3.1.a Feed, feed conversion and trophic levels

Is eating animals inefficient?

If efficiency is defined as the ratio of feed energy *in* to food energy *out* then from one perspective, all animal production is inherently inefficient. We eat animals that eat plants; arguably we could omit a whole trophic level and eat plants directly. Far less land and far fewer inputs would be needed if humans only consumed plants. Land unsuited to crop cultivation could be put to bioenergy production, afforested or rewilded – that is, left to revert to its natural, uncultivated state. Agricultural byproducts could be converted into bioenergy or even, with sufficient investment, into human food. The charge of fundamental inefficiency sits at the heart of much anti-meat advocacy.

Others reject this view as overly simplistic given the multiplicity of animal types and production systems, as well as practical considerations regarding people's differing access to particular foods, the nutritional value of animal products, the suitability of different lands for particular forms of food production and the role of livestock production in the recycling of nutrients.

Thus from a second perspective, a ruminant feeding on unfertilised, unirrigated, natural grass and producing meat or milk or traction power is perfectly efficient – it creates something from nothing, providing the ultimate free lunch. This standpoint highlights the metabolic miracle that is the cow's rumen, pointing out that the animal is reared on land unsuited to other food- producing purposes and consumes no human-edible food. What is more, the cow produces not only meat or milk but also other goods such as leather (and sheep, wool), phosphorus (in the form of bonemeal) as well as glues. The animal's positive role in shaping and maintaining landscapes and their species diversity may also be highlighted.

A third standpoint does not reject animal production – but rejects what it defines as inefficient production. This perspective sees the pasture-reared cow as a leaky bag of wind while the intensively reared chicken is now the paragon of efficiency. With its metabolism, far less feed energy (and associated land) is required to produce meat than the grass-fed cow. Although intensively reared poultry rely strongly on edible feed grains, the conversion efficiency is about two and the foods obtained (meat, eggs) are not only in demand but are rich in protein and micronutrients. The feathers can be processed into a high protein feed ingredient or burned and used to produce energy, while the concentrated piles of manure that are generated can be anaerobically digested to produce energy and a nitrogen-rich fertiliser.

These three views on the efficiency with which animals consume feed to provide food are founded on different views about the value and legitimacy of different feed sources, their uses and counter- uses, as well as the way they are metabolised by different animals. All are also influenced, however subtly, by the values people bring to their assumptions about counterfactual uses for land or resources, their attitudes to humanity's place in the natural environment, and about the malleability of the economic status quo. Some of the main differences in perspective are discussed in the sub sections that follow.

Animals and their consumption of human edible feed

Three sorts of questions tend to be debated here. First, could the feed consumed by animals be eaten directly by humans – for example human edible grains, or fishmeal from edible fish? Second, how efficiently does the animal convert that food into edible products – i.e. milk, flesh, eggs? And third, does the conversion of plant feed into animal product (milk, meat etc.) deliver desired nutrients more effectively to humans than if the plants were to be consumed directly by humans?

Today farmed animals consume about 36% of all cereals produced, or 42% of all coarse grains – these include barley, oats, sorghum, millet, maize, rye and so forth.[10] In the context of a rising human population and constraints on good quality arable land, the use of formulated feedstuffs based on human edible foods is seen, by industrial farming's critics, to undermine rather than enhance food security by competing with

[10] Alexandratos N and Bruinsma J (2012). World agriculture towards 2030/2050: the 2012 revision Global Perspective Studies Team, ESA Working Paper No. 12-03, *Agricultural Development*, FAO Agricultural Development Economics Division, Food and Agriculture Organisation, Rome.

the food grain market and pushing up prices, and also contributing to indirect land use change. Monogastrics, which consume 78% of feed grains produced, are particularly vilified.[11]

However the livestock industry and its advocates point out that recent decades have seen huge increases in the efficiency with which feed grains are converted to animal product.[12] Breeding efforts have produced animals that portion more of their food energy into outputs that we want (muscle, milk, eggs), and less into those we do not (fat, or expenditure on overall body maintenance); confined housing systems that that make it possible to control and monitor animals; and carefully calibrated feed formulations help increase feed conversion efficiency. These feeds may themselves be the product of breeding programmes geared at improving nutritional value (e.g. higher in protein, or with fewer anti nutritional compounds). They are highly digestible and so less energy is expended in digesting them, a process that in ruminants also generates methane. The outcome of this breed-feed-housing combination is that fewer GHG emissions are generated per given quantity of food output produced than animals reared in more extensive systems – and feed conversion efficiencies are extremely high. In the case of intensively reared chicken it can take as little as 1.8 kg of feed to produce 1 kg of (live) chicken.[13] This, it is pointed out, represents nutritional value for money, since animal products are rich not only in protein but also in bioavailable micronutrients (discussed above in Section 3). They also point out that while feed grains *could* be fed directly to humans, their quality may be poor. For example feed grade wheat has a lower gluten content, making it less suitable for producing the airy loaves to which we have now become accustomed. And while wheat is used as an animal feed the bulk is in fact made up of coarse grains such as maize, barley and sorghum. Maize is valued as a food staple in some countries, but not in others. As for sorghum and barley, when circumstances are straitened these are foods that are eaten by, and considered fit for humans, but people tend to move on to more popular or prestigious grains such as wheat or rice as soon as they can afford to, even though the nutritional profiles of all these grains are very similar.

As to the argument that feeding grains to animals pushes up prices and undermines food security, a counter-view holds that demand for feeds stimulates technical improvements, leading both to arable yield increases and to greater animal breeding efficiencies. There is evidence to suggest, for example, that the growth in demand for animal feed is unlikely to affect grain prices significantly in coming years,[14] although of course much depends on the assumptions underpinning these economic models. And while apologists for industrial animal agriculture may articulate all the arguments outlined above, it is increasingly accepted that alternative feed sources are needed, especially since the main feedstuffs used are often produced in locations distant from where livestock production is growing most rapidly. Efforts are underway to

11 Herrero M, Havlik P, Valin H, Notenbaert A, Rufino MC, Thornton PK, Blümmel M, Wiess F, Grace D and Obersteiner M (2013). Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems, *PNAS*, 110, 52, 20888–20893

12 Capper J. L., Cady R. A. and Bauman D. E. (2009). The environmental impact of dairy production: 1944 compared with 2007 *Anim Sci*, 87:2160-2167

13 Patel S, Raval A, Bhagwat S, Sadrasaniya D, Patel A, Joshi S (2015) Effects of Probiotics Supplementation on Growth Performance, Feed Conversion Ratio and Economics of Broilers. *Journal of Animal Research* 5(1): 155-160

14 ODI (2014). Future Diets. Overseas Development Institute, London, UK.
Available at: www.odi.org.uk/.../odi.../odi.../8773.pdf

develop feeds derived from materials that include grass, insects, yeasts or algae, that currently compete less with direct human demand and in some cases are being used commercially.[15,16,17]

Within the fish sector, the issues are somewhat different in that the use of human edible feeds often replaces the use of wild-fish based feed inputs, such as fishmeal and fish oil. The role of fishmeal is now declining but nevertheless 17-30% of all wild fish captured is still converted into fishmeal, to feed farmed animals, with aquaculture the main user today.[18,19,20]

Commentators often highlight the intuitive illogicality of turning fish into fish, incurring both fossil fuel and feed conversion energy costs, and often harmful environmental and ethical consequences. Overfishing is a perennial concern and many fish stocks are over-exploited; this not only reduces the stability of wild fish stocks but also has knock on effects for seabirds and mammals.[21] The fishing of species used for fishmeal in commercial production can also, it is argued, undermine the food security of subsistence oriented fisherfolk.

But others counter this position by arguing that the use of fishmeal actually makes more fish available for human consumption than would otherwise be the case. Fishmeal can be made from 'industrial' fish such as sand eels that are not usually eaten by humans. The non edible is thereby converted into the edible (albeit incurring some energy costs), an argument similar to 'cows make milk from grass' discussed in the next sub-section).

But fishmeal is also made from human-edible fish such as anchovy. The fishmeal industry's response here is that while technically these *can* be consumed by humans there is often little in demand for them, or else the market may be located distant from source. It is costly and logistically difficult to store fish whole for human sale and far easier to process them into a more stable product, fish meal.[22] What is more,

15 European Commission, (2013) Sustainable Food Security, Horizon 2020, Available at: https://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/topics/2320-sfs-01a-2014.html

16 PROteINSECT, European Commission, Available at: http://www.proteinsect.eu/

17 van Krimpen, M. M., Bikker, P., van der Meer, I. M., van der Peet, Schwering, C.M.C., Vereijken, J. M., (2013) Wageningen UR, Livestock Research Partner in livestock innovations Cultivation, processing and nutritional aspects for pigs and poultry of European protein sources as alternatives for imported soybean products, Report 662: http://edepot.wur.nl/250643

18 Olsen R L and Hasan M R (2012). A limited supply of fishmeal: Impact on future increases in global aquaculture production Trends in Food Science & Technology 27 (2012) 120e128

19 Olsen RL, Toppe J and Karunasagar I (2014). Challenges and realistic opportunities in the use of by-products from processing of fish and shellfish Trends in Food Science & Technology 36 144e151

20 Olsen R L and Hasan M R (2012). A limited supply of fishmeal: Impact on future increases in global aquaculture production Trends in Food Science & Technology 27 (2012) 120e128

21 Cury P.M Boyd, I.L., Bonhommeau, S., Anker-Nilssen, T., Crawford, R.J.M., Furness, R.W., Mills, J.A., Murphy, E.J., Österblom, H., Paleczny, M., Piatt, J.F., Roux, J.P., Shannon, L., Sydeman, W.J. (2011). Global Seabird Response to Forage Fish Depletion--One-Third for the birds. *Science* 334, 1703

22 Wijkström, U.N. (2012). Is feeding fish with fish a viable practice? In R.P. Subasinghe, J.R. Arthur, D.M. Bartley, S.S. De Silva, M. Halwart, N. Hishamunda, C.V. Mohan & P. Sorgeloos, eds. Farming the Waters for People and Food. *Proceedings of the Global Conference on* Aquaculture 2010, Phuket, Thailand. 22–25 September 2010. pp. 33–55. FAO, Rome and NACA, Bangkok.

fishmeal is also made from fish-guts and other byproducts from wild and farmed fish; when these and other ingredients (including some arable grains), are added to the formulation, one finds – and industry points out – that aquaculture in fact produces 1.92 tonnes of harvestable product for every tonne of whole wild fish caught.[23]

However it is worth noting that the availability of fish meal may also reflect inefficient carcass utilisation – better filleting might increase the proportion available for direct human consumption, reducing the quantity that can be processed into fishmeal.

Whatever the position held, the fact is that in recent years the price of fishmeal has increased dramatically, reflecting scarcity, the tightening of quotas and regulations and, to a lesser extent, increased direct human consumption of some of the pelagic fish traditionally reduced to fishmeal.[24] The consequences are twofold. First fishmeal tends to be reserved for high value aquaculture production rather than for lower value terrestrial livestock. Second, the aquatic sector is now actively seeking out and using alternative, cheaper protein sources. Even carnivorous species such as shrimp and salmon now consume diets that can contain up to 50% plant protein.[25] It could be argued that it is preferable to use soy than wild fish.[26] But the 'merits' of soy depend on what alternative possible scenario are envisaged: from one standpoint, feeding soy represents an improvement on a business-as-usual situation in which marine resources are overexploited; from another, the mainstreaming of soy compares unfavourably with an alternative scenario in which fish are reared at relatively low levels of intensity using byproducts, or in unfed (extensive) systems.

Non-human edible feeds: grass, byproducts and their counterfactual uses

It is often argued that systems in which animals consume grass grown on land unsuited to cropping, and/or byproducts such as plant stovers, rice bran husks, food wastes and, more controversially, meat and bone meal (MBM) for omnivores, are more truly efficient, despite higher feed conversion ratios and – discussed below – their higher carbon footprints. Since there is no competition for resources between humans and animals this 'ecological leftovers' approach[27] achieves perfect feed conversion efficiency, in that 'nothing' is transformed into something, and a problem into a solution. If we did not rear animals on grass or byproducts, additional arable land would need to be cultivated to obtain an equivalent amount of nutrition, whether measured in terms of calories, protein or specified micronutrient. This might entail land use change and associated environmental impacts and of course there may be environmental costs associated with inputs such as fertiliser.

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[23] Jackson A. (undated). Fish In – Fish Out (FIFO) Ratios explained. International Fishmeal and Fish-oil Organisation. Available at: http://www.iffo.net/cn/system/files/100.pdf

[24] Tacon, A. G. J., Hasan, M. R., & Metian, M. (2011). Demand and supply of feed ingredients for farmed fish and crustaceans – Trends and prospects. FAO Fisheries and Aquaculture Technical Paper No. 564. Rome: FAO.

[25] Olsen R L and Hasan M R (2012). A limited supply of fishmeal: Impact on future increases in global aquaculture production Trends in Food Science & Technology 27 120e128

[26] Pelletier N, and Tyedmers P. (2007). Feeding farmed salmon: Is organic better? *Aquaculture* 272 399–416

[27] Garnett T. (2009). Livestock-related greenhouse gas emissions: impacts and options for policy makers, Environmental Science & Policy, 12, Issue 4, 491–503

However, a vegan perspective might challenge this notion of cyclical perfection. For a start, how much of these feeds (grass, byproducts) does an animal consume as compared with other feed inputs; and how efficiently does it convert them into edible products? Might an alternative use be considered? Could byproducts, currently deemed inedible, be processed and transformed into human edible food, given technological investment?

As to the first question, animals differ in their ability to consume grass and byproducts and in line with the no-free lunch principle; resource effectiveness carries a metabolic cost. Thus while ruminants can digest coarse and fibrous products (even pigs can consume some silage), this undertaking entails greater energy expenditure than the consumption of highly digestible feeds. Additionally the microorganisms in their guts (which aid this digestive process) respire methane.

There are also practical limitations. For a start, certain approaches to closing the resource loop, such as by feeding meat and bone meal to monogastrics (traditionally omnivores), is limited by regulations in many parts of the world.[28] An even more fundamental challenge to the 'something from nothing' argument is that it ignores counterfactual possibilities. Even rough grazing land potentially has alternative uses. It could be left to rewild, so delivering biodiversity and carbon sequestration benefits.[29] Or it could be used to grow energy crops -scrubby trees or even potentially grass – options that are increasingly technically viable.[30] The feasibility and environmental merits of these alternative land uses will depend on factors such as transport infrastructure (for example the energy needed to harvest and transport biomass with low energy density), cost and technological ability. But the value of using land for one thing over another also depends on what society decides it wants and needs and the extent to which its views are (or are not) effectively communicated via market signals and a governance framework.

Much also hinges on how one defines a 'byproduct' and how this definition alters across societies and over time. The 'hierarchy of waste' concept, based on environmental resource use efficiency has a bearing on how one might approach this question. This hierarchy prioritises the use of human edible food for humans over animals, and then for animals over industrial uses (see Figure 1). But its theoretical simplicity is complicated by multiple cultural, economic, technological and practical factors. As noted above, consumption norms (influenced by culture and affluence) shape our views on what we consider to be edible.

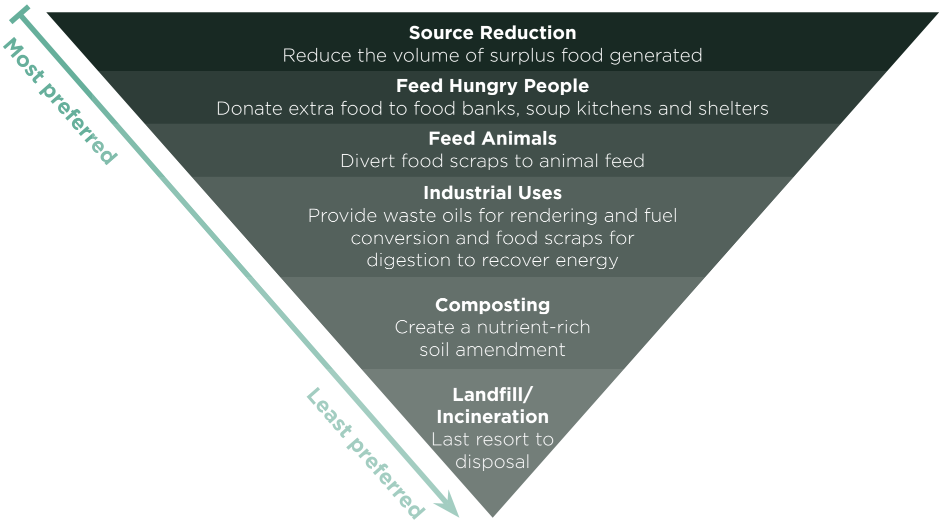
The definition of a byproduct can change over time too. For example whey has traditionally been fed to pigs, but it is increasingly processed into foods for humans and marketed as a highly nutritious product and an aid to weight loss. It could be argued that it is more 'efficient' for us to drink whey directly than use it as a pig feed. Equally, the merits of using byproducts to feed animals than for, say, industrial purposes or as an energy feedstock in anaerobic digestion, depends on the value one

28 For example: EU, 2011. Commission Regulation No 142/2011 of the European Parliament and of the Council laying down health rules as regards animal by-products and derived products not intended for human consumption.

29 Monbiot G (2013). Feral: Searching for Enchantment on the Frontiers of Rewilding, Allen Lane

30 Gelfand, I., Sahajpal, R., Zhang, X., Izaurralde, R. C., Gross, K. L., & Robertson, G. P. (2013). Sustainable bioenergy production from marginal lands in the US Midwest. Nature, 493(7433), 514-517. doi:10.1038/nature11811 Available at: http://www.nature.com/nature/journal/v493/n7433/abs/nature11811.html#supplementary-information

Figure 1. Food recovery hierarchy



Source: US Environmental Protection Agency http://www.epa.gov/foodrecovery/

assigns to non food products (eating meat versus having a renewable source of energy); this will be shaped by societal norms and for some, ethical considerations.

As technology develops so too the possibilities for transforming wastes into valued products change. For example it may be possible to convert oil seed cake into human edible products, extract nutrients from them, or to use human-inedible byproducts as substrates for yeast or fungus based proteins. Note finally that the 'byproducts' question applies also to the byproducts of the animal itself – for example animal fats can be rendered and used as a fuel source.

Leverage effect

A further twist in considerations around feed and efficiency concerns the 'leverage' effect of high quality grains. The question here is whether feeding some of these in combination with coarser byproducts harnesses greater levels of productivity, such that the environmental benefits of feeding grains more than compensate for the environmental costs of their use. In other words is the 'sacrifice' of human edible feed catalytic, releasing the value of human inedible feed so that the gains (measured using various output metrics – see below) are considerably more than would be achieved through the use of the latter alone? The leveraging effect of using marine ingredients in aquaculture production has already been discussed above.

In the terrestrial sector, this leveraging argument may be more relevant to ruminant production than to monogastrics since the latter require more digestible feeds, and as such are inherently grain dependent, at least at scale (the traditional household pig would have been fed largely on scraps and digestible byproducts such as whey). It is likely that this catalytic effect only occurs at low levels of quality feed use; beyond a certain threshold, the productivity gains diminish and environmental costs mount up. Least (economic) cost formulations already take this law of diminishing returns into account, but it is likely that the environmentally versus economically optimal levels of feed input will differ. The challenge of course is to define what 'environmentally optimal' actually is – the definition will inevitably vary by context.

Extending the 'leveraging' concept more widely to human diets, one could ask whether there may be an optimum level of animal product consumption, such that the nutritional gains obtained are not outweighed by the environmental costs. In other words, might a defined – certainly low – quantity of nutrient-dense animal products in a largely plant-based diet be more land, resource, or greenhouse gas-efficient than an entirely plant-based diet? To give an exaggerated and purely illustrative example, instead of eating 2kg of broccoli to obtain all the micronutrients we need might adding 20g of meat to the diet reduce the broccoli requirement to, say, 1kg, meaning that fewer negative impacts overall are generated than under the 2kg scenario? As already observed, the 'answer' to this question will depend upon the type of animal product, how the opportunity costs of the feed inputs (byproducts, rough grassland or grains) are assessed, the choice of plant foods and the overall diversity of the diet.

Metabolism, physiology and multifunctionality

As noted, some animals are more metabolically efficient than others. Simplifying somewhat, cold blooded species such as fish convert feed energy to food more efficiently than warm blooded animals (although there are overlaps between certain fish species and poultry), and monogastrics more so than ruminants, bearing in mind all the provisos discussed above about the feed source.

However this generalisation masks several complexities. For a start, the efficiency with which an animal utilises food in ways useful to humans depends not just on its metabolism but on other aspects of its physiology. Some animals have a greater proportion of inedible parts such as bones than others (although these may also have uses as discussed below); while the nutritional quality of what is edible may also vary (see Box 1 below), affecting judgements as to efficiency. Some animals – small fish for instance – can be eaten whole; this is not just resource efficient but also adds nutritional value since the bones and viscera are particularly nutrient-rich.

Turning back to edible outputs, the proportion of the overall carcass that is technically edible to humans varies by animal species; and of that edible proportion, the fraction judged to be acceptable as such will vary by culture (see Box 1).

Byproducts that are technically fit for human consumption but for which there is no market may be used in other ways, such as pet food. Is this resource efficient? The processing of viscera and so forth in this way undoubtedly makes use of unwanted resources and so 'saves' on the need to use additional carcass meat for pets. However, in the absence of commercially available prepared food, domestic pets could eat mice or kitchen scraps – in which case pet food does not represent a saving at all. The reliance on human edible meat may be generating its own environmental rebound effects, by encouraging people to think about the quality of their pets' diets in almost human terms. In mature markets, such as the in Northern Europe the US, pet owners are increasingly buying resource- and energy-demanding 'premium,' including chilled and fresh pet foods.[31,32,33]

As to non edible parts of the body, many of these are also of use. Examples from the terrestrial sector include wool or fur, leather from skin; fat (i.e. that which is not consumed) which may be used as a bioenergy feedstock, and bones, which can be

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31 Woo, C., Organics, Raw Meat, and Designer Diets: New Trends in Dog Food, The Bark, Available at: http://thebark.com/content/organics-raw-meat-and-designer-diets-new-trends-dog-food

32 Fresh pet, Available at: http://freshpet.com/

33 Wonderboo, Available at: http://www.wonderboo.com/

Box 1: Edible efficiency of different animal species and parts

Table 2 takes data from Nijdam *et al* (2012)[34] to calculate the 'edible efficiency' of the live animal i.e. the fraction of the animal that is eaten. While the differences across broad animal types do not appear to vary hugely, there are significant variations between different species of the same animal type. For instance, in the aquatic sector, the flesh yield from tilapia is only 30-35% as compared with salmon, where it can be as high as 70%. Animals that are thinner, or with a higher fat-muscle ratio will have a lower edible efficiency than well-conformed animals, a point that underlines both the importance of breeding efforts in modifying feed conversion efficiencies and the cultural preference, over time, for leaner meat. Technically fat is 'edible' but increasingly we prefer not to eat it. Other uses can be found for it however, as discussed below.

Table 2: Edible efficiency per meat type

	Beef %	Pork	Mutton	Poultry	Fish
Killing out factor (carcass weight as percentage of live weight)	53	75	46	70	40
Boneless meat yield (edible meat out of carcass weight)%	70	75	75	80	100
Edible efficiency %	**0.37**	**0.56**	**0.35**	**0.56**	**0.4**

Source: first two rows taken from Nijdam *et al* 2012

The importance of cultural norms in defining edibility is just as strong when it comes to blood and offal. Both can be highly nutritious, and have historically been part of Western diets. However their consumption has declined considerably – data for blood products are not available but offal consumption has fallen by 12-fold in the UK in the last 30 years.[35] This is not to say that offal is wasted. Some enters the food chain in the form of processed meats such as sausage. Additionally, a global trade exists in offal and other animal parts such as heads and feet, because in many regions of the world they are still acceptable and indeed liked as foods. Of course transport costs need to be born in mind both from an environmental and an economic perspective. However the processes of globalisation may in time alter overseas preferences such that the demand for these foods dwindles – in which case trade's role in improving resource efficiencies may diminish.

Some processed animal parts (PAP) are not edible to humans or to most animal species; but may be permitted as feeds depending upon the legislative context. In Europe for example, MBM may be fed to aquatic species but not to terrestrials, following the outbreak of BSE. Note that this legislative constraint, however necessary, has had environmental knock on effects; one study finds a link between the introduction of the 2001 EU-wide ban on the use of animal byproducts and the increase in demand for Amazonian soy with its attendant 8
environmental harms.[36] Thus health and safety requirements have led to an 9
arguably necessary loss in resource efficiency.

[34] Nijdam D, Rood T and Westhoek H (2012). The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes Food Policy 37 (2012) *760–770*

[35] DEFRA Family Food datasets 1974-2013 Available at: https://www.gov.uk/government/statistics/family-food-2013

[36] Elferink EV, Nonhebel S, Schoot Uiterkamp AJM (2007). Does the Amazon suffer from BSE prevention? *Agriculture, Ecosystems and Environment 120*

ground up and used as a soil fertiliser. In the aquatic sector there is particular interest in the potential for extracting ingredients with higher economic value – for example fish fats for biofuel production, or collagen, gelatine, chitosan and peptides for use in a range of biomedical, food industry, animal feed industry and cosmetic applications. Fish parts and non edible byproducts such as mussel shells can be used in the manufacture of compost or as a soil fertiliser.[37,38]

How does thinking about these non food outputs affect our understanding of feed conversion efficiencies? Arguably many of these non food outputs are essential – humans have many uses for a resilient, flexible waterproof material such as leather, or for warm insulating fibres such as wool. In the absence of livestock, we would have to manufacture them from other materials, whether petroleum or plant based. This said, substantially less land is needed to produce plant-based alternatives to animal by-products than to produce animal feed; if the availability of these by-products declines because of a fall in livestock production, the land spared from animal farming is more than sufficient to produce non food substitutes – and when it comes to ruminant by-products, methane emissions are also omitted. For example, the production of 1 tonne of bioplastics requires 0.2-0.3 ha,[39] while a bull in an intensive system would require a similar area for feed production but generate only 35 kg of skin for leather, or thereabouts. To make fair comparisons, post-farm production stages must also be included, but both animal, plant and petroleum based products require energy and chemicals for preparation into usable products.[40] Of course, if livestock are being reared anyway, it makes sense to use the animal by-products rather than to waste them and produce additional biomaterials.

It is also worth noting that many non-food livestock outputs are produced surplus to requirements – wool for example has a very low market value. This may reflect dwindling demand for the particular properties that wool provides; in 2014 wool accounted for just 1.3% of a global fibre market in which synthetics dominate.[41] Thus the value of these non food products to society changes over time as alternatives become available. A case can moreover be made that some livestock generated byproducts do not so much meet existing demand (or need) as create new demand – cosmeceuticals being a case in point. Do these byproducts genuinely provide a solution to a resource problem, or is a market artificially created, to which they then cater, using energy and other inputs in the process? In other words does supply stimulate demand – potentially demand over and above the original availability of

37 Thrane M. 2004. Environmental impacts from Danish fish products: hot spots and environmental policies. Doctoral thesis, Aalborg University

38 Newton, R Telfer, T and Little, D.C. (2014) Perspectives on the utilisation of aquaculture co-product in Europe and Asia: prospects for value addition and improved resource efficiency, *Critical Reviews in Food Science and Nutrition* 54:4, 495-510

39 Piemonte, V., Gironi, F., (2011) Land-use change emissions: How green are the bioplastics? *Environmental Progress & Sustainable Energy* Vol 30, Issue 4, pages 685–691DOI: 10.1002/ep.10518 Available at: http://onlinelibrary.wiley.com/doi/10.1002/ep.10518/full

40 Turley, D. B., Horne, M., Blackburn, R. S., Stott E., Laybourn, S. R., Copeland, J. E, and Harwood, J. 2009. The role and business case for existing and emerging fibres in sustainable clothing: final report to the Department for Environment, Food and Rural Affairs (Defra), London, UK.

41 IWTO (2014). Market Information: 2014 Edition. Statistics for the global wool production and textile industry. Prepared by Poimena Analysis & Delta Consultants. International Wool Textile Organisation.

supply – in which case it becomes a driver of production in their own right? Much depends on what goods and services we decide to value.

Practical or cost difficulties may also limit the potential for extracting more value from byproducts. For example, in the wild fish sector, viscera and so forth are highly perishable. One technically feasible option is to ensile them, a process that yields a fermented fish product of high nutritional quality. However, the market price obtained may not often justify the costs incurred. As for the commercial production of high value bioactive compounds, constraints include: a lack of existing markets, the fact that high quality byproducts are not always regularly available, the high costs of isolating specific compounds, the challenges connected with providing the documentation required for a potential nutraceutical product and the ability to produce, more cheaply, equivalent compounds either by chemical synthesis or genetic modification.[42]

Ultimately, discussions about byproducts raise questions about what the outputs *are* of animal production and how different stakeholders value them. These are discussed further in 3.3 *Efficiency in relation to outputs*.

3.1.b Efficiency and land use

The obvious point to make about land is that it is finite. While more land could still be cleared and cultivated, the consequences for deforestation, soil and biomass carbon release (generating GHG emissions) and biodiversity loss, are likely to be catastrophic. Most people agree that future food production needs to confine itself to existing agricultural land, without encroaching further onto uncultivated areas. Any increases in food output will therefore have to be achieved through productivity improvements -through 'sustainable intensification,' a controversial concept, discussed further in 3.3.b. *Environmental value*. Conversely or additionally, the need for agricultural land may be kept constant by moderating our demand for land-hungry foods such as meat – an equally contested option discussed in 3.3.a *Food and nutrition*.[43,44]

But environmental issues associated with land use relate to not just to the *quantity* of the land used, but also its *quality*, its *change in condition* as a result of using it to rear animals, the environmental *knock-on effects* for land elsewhere, and the *opportunity costs* of using that land for animal farming rather than for some other purpose (Box 2).

Both terrestrial and aquatic livestock affect both land and land use, although far more attention has been paid to the former, given their scale of their impact. In all it is estimated that terrestrial livestock production uses 70% of agricultural land world wide, a figure that includes one third of all arable land[45] through their use of grains and

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[42] Olsen R L and Hasan M R (2012). A limited supply of fishmeal: Impact on future increases in global aquaculture production, *Trends in Food Science & Technology* 27 (2012) 120e128

[43] Garnett T, Appleby M C, Balmford A, Bateman I J, Benton T G, Bloomer P, Burlingame B, Dawkins M, Dolan L, Fraser D, Herrero M, Hoffman I, Smith P, Thornton P K, Toulmin C, Vermeulen S J and Godfray H C J (2013). Sustainable Intensification in Agriculture: Premises and Policies, *Science,* 34, 6141, 33-34

[44] Bajželj, B., Richards, K. S., Allwood, J. M., Smith, P., Dennis, J. S., Curmi, E., & Gilligan, C. A. (2014). Importance of food-demand management for climate mitigation. *Nature Clim. Change*, 4(10), 924-929

[45] Alexandratos N and Bruinsma J (2012). World agriculture towards 2030/2050: the 2012 revision Global Perspective Studies Team, ESA Working Paper No. 12-03, Agricultural Development, FAO Agricultural Development Economics Division, Food and Agriculture Organisation, Rome.

Box 2: Issues around land use and the environment

Quantity of land used: The amount of land used by any given activity is critical, given land's finite availability and the damage associated with the conversion of uncultivated land.

Quality of land used: Different kinds of land are suited to different purposes. Salinised soils, or nutrient poor grasslands with high biodiversity values may not be suitable for crop production. Fertile soils are in short supply and so the question to consider is what they should most optimally be used for – to grow crops for human consumption, for feed, or for bioenergy.

Change in baseline condition: Environmental changes may arise as a consequence of animal production, potentially measured across a range of indicators including soil organic carbon, biodiversity or water holding capacity. Environmental changes may also arise from a move away from animal production (eg. conversion into arable land, rewilding etc.).

Knock on effects of its use: These are the impacts that an activity indirectly has on land use elsewhere; this can occur through displacement effects or more directly because nutrient run offs on agricultural land seep onto neighbouring land which may or may not be cultivated.

The opportunity cost of land use; counterfactual alternatives: Land used directly or indirectly for livestock cannot generally be used for something else (although there are exceptions – for example solar panels can be sited on grazing land, while water used for aquaculture can be recycled for other purposes). Depending on the metric used, it may or may not be 'worth' using land for livestock production. Metrics might relate to the economics of the activity (jobs, profit), the environment (rewilding, carbon sequestration, bioenergy production), or nutrition (calories, protein or micronutrient); different metrics yield different balances of gains and costs.

oilseeds. The aquatic sector's share is unquantified but since is uses only an estimated 4% of all feedcrops[46] and land requirements for ponds and so forth are minimal, the overall figure is likely to be low.

The use of land for livestock rearing is dynamic since growth in the sector causes both direct and indirect land use change: direct where land is cleared to rear grazing animals or produce feed crops, and indirect when land used for a different agricultural purpose is reallocated to animal grazing or feed production, so displacing the original agricultural activity onto uncultivated land elsewhere. The latter relationship is poorly

[46] Troell, M., Rosamond L. Naylor, M. Metian, M. Beveridge, P. Tyedmers, C. Folke, K. Arrow, S. Barrett, A-S. Crépin, P. Ehrlich, Å. Gren, N. Kautsky, S. Levin, K. Nyborg, H. Österblom, S. Polasky, M. Scheffer, B. Walker, T. Xepapadeas, A. de Zeeuw (2014). Does Aquaculture Add Resilience to the Global Food System? *PNAS*, 111, 37, 13257–13263

understood. Recent years have in fact seen deforestation rates falling,[47] reflecting, almost entirely tighter controls in South America, particularly Brazil, although it now appears that they have started to rise again.[48,49,50]

The land-related impacts of livestock on the environment (see Box 2) differ by animal type and production systems. Grazing animals are the main cause of direct deforestation, although the contribution here is localised and has been most significant in South America.[51,52] But while encroachment onto virgin land will certainly have damaging effects, the role of livestock on land already in cultivation may be either damaging or beneficial, depending upon pre existing baseline conditions and of course what aspects of the environment one chooses to value. Poor management and overgrazing can cause soil degradation, organic carbon losses and nutrient pollution. However some studies suggest that certain grazing regimes can even increase soil carbon uptakes – although a robust evidence base is lacking and further research is needed. Moreover extensive grazing systems can also play an important role in maintaining the wild species diversity and ecological character of many regions that we have come to value.[53] In traditional mixed crop-livestock systems, manure played an important role in maintaining soil fertility; how this might affect one's understanding of efficiency is discussed further in 3.1.d *Other inputs* below.

Monogastric species require much less land overall but more high quality land, via their dependence on grain feeds. Intensively reared ruminants share certain characteristics with monogastrics in that they are fed grains and oilseeds, and in some systems may be reared in confined, zero-grazing conditions. Although milk and meat from intensively reared ruminants generally show a lower GHG footprint than their more extensively reared counterparts (discussed below), viewed from the perspective of arable land use it could be argued that they inhabit the worst and least efficient of both worlds: unlike their extensive cousins they do not utilise 'waste' land and resources, and because of their metabolism they produce far more GHG emissions than do monogastrics.

The aquatic sector's direct use of land is far smaller than that of terrestrial livestock. Nevertheless, poorly designed aquaculture developments can punch above their

47 Tubiello, FN., Salvatore, M., Ferrara, AF., House, J., Federici, S., Rossi, S., Biancalani, R., Condor Golec, RD., Jacobs, H., Flammini, A., Prosperi, P., Cardenas-Galindo, P., Schmidhuber, J., Sanz Sanchez, MJ., Srivastava, N. & Smith, P. (in press). 'The Contribution of Agriculture, Forestry and other Land Use activities to Global Warming, 1990-2012'. *Global Change Biology* doi: 10.1111/gcb.12865

48 Redd monitor, What next? Brazil's deforestation soared by 290% in September 2014, Available at: http://www.redd-monitor.org/2014/10/31/what-next-brazils-deforestation-soared-by-290-in-september-2014/

49 Imazon, Deforestation report for the Brazilian amazon (May 2015) SAD, Available at: http://imazon.org.br/publicacoes/deforestation-report-for-the-brazilian-amazon-may-2015-sad/?lang=en

50 Global Forest Watch, Country Brazil, Available at: http://www.globalforestwatch.org/country/BRA

51 Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A. & Tempio, G. (2013) Tackling climate change through livestock – A global assessment of emissions and mitigation *opportunities.* Food and Agriculture Organization of the United Nations (FAO), Rome.

52 Gibbs, H. K., Munger, J., Roe, J. L., Barreto, P., Pereira, R., Christie, M., Amaral, T., Walker, N. F., (2015). Did Ranchers and Slaughterhouses Respond to Zero-Deforestation Agreements in the Brazilian Amazon? *Conservation letters*. 0(0), 1–

53 Gibon, (2005). Managing grassland for production, the environment and the landscape. Challenges at the farm and the landscape level. *Livestock Production Science*, 96 (1), 11-31. O.P Ostermann. (1998). The need for management of nature conservation sites designated under Natura 2000 *Journal of Applied Ecology*, 35 (1998), pp. 968–973

weight, damage wise, if situated in ecologically vulnerable areas such as wetlands, both inland and coastal. For example, there has been widespread and high profile criticism of commercial aquaculture's role in the loss of mangroves. Commercial aquaculture has indeed been identified as the main driver of mangrove deforestation in many countries; for example, one eight-country remote sensing study finds that since the 1970s, commercial aquaculture has accounted for 54% of all mangrove loss.[54]

Other studies point to a much broader range of drivers for mangrove deterioration and loss. For example Ibhraim et al (2015)[55] found that oil palm and other dry land plantation were far more important causes in one area of Peninsula Malaysia. Moreover, the industry argues that more recently considerable efforts have been made to address these concerns and that commercial aquaculture can actually have a positive role to play in providing livelihoods, relieving pressure on wild fish stocks. For example, recent work in Southern Europe finds that extensive aquaculture holds can potentially help restore coastal and estuarine wetlands.[56] In Spain's Donana Natural Park 3,000 ha of lagoons have been constructed on previously drained wetlands since 1990. These lagoons are used for extensive aquaculture production but also managed for wildlife; 100 purpose-built islands have been built in the lagoons that provide nesting sites and shelter for the birdlife.[57,58]

3.1.c. Efficiency and water

Animals use water directly, for drinking, washing and (for aquatics) as their living medium. More significantly they also use water indirectly by consuming grass or other feeds, that need water to grow. The sum of an animal's direct and indirect water use is its 'virtual' or embedded use.

Metrics are being developed to capture the water related impacts of food and non-food products and to differentiate between different types of water use since not all usages have the same environmental implications (Box 3).

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54 Hamilton S (2013) Assessing the Role of Commercial Aquaculture in Displacing Mangrove Forest. *Bulletin of Marine* Science 89(2):585-601

55 Ibharim N A, Mustapha M A, Lihan T and Mazlan A G. (2015). Mapping mangrove changes in the Matang Mangrove Forest using multi temporal satellite imageries *Ocean & Coastal Management* 114 (2015) 64e76

56 Walton M.E.M., Vilas C, Coccia C, Green A.J., Canavate J.P., Prieto A, van Bergeijk S.A., Medialdea J.M., Kennedy H, King J, Le Vay L. (2015) The effect of water management on extensive aquaculture food webs in the reconstructed wetlands of the Donana Natural Park, Southern Spain. *Aquaculture*. doi: 10.1016/j.aquaculture.2015.06.011

57 Walton M.E.M., Vilas C, Coccia C, Green A.J., Canavate J.P., Prieto A, van Bergeijk S.A., Medialdea J.M., Kennedy H, King J, Le Vay L. (2015) The effect of water management on extensive aquaculture food webs in the reconstructed wetlands of the Donana Natural Park, Southern Spain. *Aquaculture*. doi: 10.1016/j.aquaculture.2015.06.011

58 Walton M.E.M., Vilas C, Canavate M.E.M., Gonzalez-Ortegon E, Prieto A, van Bergeijk S.A., Green S.A., Librero M, Mazuelos N, Le Vay L (2015) A model for the future: Ecosystem services provided by the aquaculture activities of Veta la Palma, Southern Spain. *Aquaculture*. doi: 10.1016/j.aquaculture.2015.06.017

Box 3: Water footprinting

Water footprinting tools quantify and make distinctions between green water (essentially rainfall), blue water (abstracted or irrigation water) and grey water (a measure of water contamination). There are important interactions between the water types -for example changes in vegetation cover in rainfed areas may affect blue water availability downstream – but arguably blue water use incurs a potentially greater opportunity cost and may cause more environmental damage, for example in the form of salinisation.[59] To these concepts should be added that of 'water scarcity' – the negative impacts of blue water use in water-scarce Morocco, say, may be greater than in the UK where it is generally more plentiful.

59 Hess, T., Andersson, U., Menab, C., Williams, A., (2015) The impact of healthier dietary scenarios on the global blue water scarcity footprint of food consumption in the UK, *Food Policy,* Volume 50, Pages 1–10

Growth in the livestock sector will increase water demands and potentially exacerbate water scarcity.[60] Much has been made, particularly by advocacy groups, of the 'thirstiness' of meat production. For instance it is sometimes said – and the numbers quoted vary widely – that it requires over 15,000 litres of water to produce 1kg of beef[61] but much of this is in the form of green water falling on grass that be growing anyway and whose use does not impact upon water availability elsewhere. Arguably, animal grazing systems, by converting green water into edible output in fact avoid the need to produce a similar amount of plant based food, potentially requiring irrigation, from somewhere else. Some research also suggests that in certain contexts such as Sub-Saharan Africa the productivity of livestock water use compares favourably with that of crops since animals can consume scrubby rain-fed plants in situations where cropping would be unfeasible.[62]

However, as animal production systems intensify, they become increasingly dependent on irrigation water for feed production. Across almost all livestock types, the more intensive the system, the greater the water demand.[63] Aquatic systems are somewhat different: in intensive aquaculture systems, large volumes of water may be required but they will not actually be consumed, and so the water is potentially available for other purposes.

In the aquatic sector, water issues with respect to feed are similar but there are additional considerations since water is the living medium and so production can alter its state. Fed aquaculture systems typically add nutrients to their culture water – this may increase or decrease its value for a secondary use, depending on what

60 Jägerskog, A., Jønch Clausen, T. (eds.) (2012). Feeding a Thirsty World – Challenges and Opportunities for a Water and Food Secure Future. Report Nr. 31. SIWI, Stockholm

61 IMECHE. (2013). *Global food: Waste not, Want not*, Institution of Mechanical Engineers

62 Peden D, Taddesse G, Haileslassie A (2009) Livestock water productivity: implications for sub-Saharan Africa. *The Rangeland Journal* 31, 187–193.

63 Mekonnen, M. M., Hoekstra, A. Y. (2012). A Global Assessment of the Water Footprint of Farm Animal Products. *Ecosystems* 15, 401-415.

that is. If water is used for irrigation, fertile water will reduce the need for additional fertilisers, but if water is to be used for domestic supply, then the nutrients may need to be removed. Un-fed filter feeding or detritus consuming species are, by contrast, removing nutrients from the water, and depending upon context this can be environmentally beneficial.

Well planned and sensitively sited ponds can also capture and store run-off water and so potentially improve the productivity of the wider agricultural system and contribute to watershed management. Such development may be of particular value in marginal, highly seasonal subtropical zones and for rainfed landscapes.

In principle then, the well managed integration of aquaculture into water infrastructure can enhance the efficiency of water use, by removing or adding nutrients as needed and by acting as a water store. In practice while this can and does happen, aquaculture developments can also cause nutrient pollution, and the water supplied to support fish production in ponds may be lost through seepage and evaporation. This may cause problems in water scarce areas where there is competition for water with other uses. Of course the embedded water requirements of feed production also need to be taken into account. Thus the efficiency or otherwise of water use in the aquaculture sector varies considerably by system and context, and these differences can lead to stakeholders drawing very different conclusions about the merits of aquaculture or of particular aquacultural systems.

3.1.d Other inputs

Other inputs to the system include energy (generally fossil fuel derived), fertilisers (synthetic and organic), biocides, crop and animal genetic resources (not to mention the animals themselves), labour, capital and other infrastructure. The concept of inputs may be extended further to include modern and traditional knowledge, ecosystem services and financial investment.

There are different views regarding the environmental legitimacy of these inputs. For example while all forms of nitrogen cause some N related leakage, not all nitrogen sources are equal in the eyes of beholders. Some stakeholders argue that synthetic nitrogen has several efficiency advantages over its biological counterparts. Unlike the latter, the former can be manufactured without the use of land and may be produced from renewable energy sources including biomass or wind[64,65] – although today it is mostly manufactured using fossil fuels. It is arguably easier to apply an accurate and optimum dose of consistently formulated synthetic fertilisers than to gauge how much manure to use, or what the effects of legume planting might be on soil nitrogen content. Less land and fewer inputs more precisely applied; this is one vision of successful and sustainable agriculture, and perhaps its logical endpoint is the landless, hydroponics-based closed loop system vertical farm. And they also point out that the Haber-Bosch process has saved lives – without synthetic nitrogen the world's growing population would have faced mass starvation.

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64 Tunå, P., Hulteberg, C., Ahlgren, S. (2013). Techno-economic assessment of nonfossil ammonia production. *Environmental Progress & Sustainable Energy* 33 (4) 1290-1297.

65 Ahlgren, S., Baky, A., Bernesson, S., Nordberg,Å., Norén, O., Hansson, P.-A. (2012), Consequential Life Cycle Assessment of Nitrogen Fertilisers Based on Biomass – a Swedish perspective. *Insciences Climate Change Journal* 2(4).

From another perspective synthetic nitrogen is inherently problematic because it is mainly produced using fossil fuels, is very easy to over apply, and because the process is capable of drawing so much nitrogen down from the atmosphere that it in effect has *diabolus ex machina* properties – it ruptures the natural order of things. The fact that many inputs to the farming process – such as synthetic fertilisers, biocides, genetic materials, farm machinery and infrastructure, access to financing – are manufactured by large and powerful organisations may also form part of the critique for those who see corporate control and power concentration as part of the story of unsustainability. According to this narrative, industrial agriculture not only damages environment but also undercuts and undermines the livelihoods of poor farmers; it provides raw inputs to large scale manufacturing enterprises further down the supply chain who profit from the production of unhealthy and unsustainable food. By contrast inputs such as organic manures and legumes, indigenous and traditional knowledge, non-commercialised genetic resources and other aspects of the natural resource base (soil quality, water quality and so forth) are assigned greater value as constituents of a different vision of environmentally and socially sustainable food systems.

3.2. Efficiency in relation to impacts

Section 3.1 considered the inputs to TAL production and inevitably strayed a little into discussion of the negative impacts and positive outputs arising. This subsection takes a closer look at just two of the negative environmental impacts arising from the TAL sector: greenhouse gas emissions and nutrient losses that cause soil and water pollution. It is also possible to consider other negative impacts here, both environmental and societal, but instead these are discussed more fully in Section 3.3, under 'outputs.' The somewhat arbitrary way in which an effect may be classed either as an 'impact' or an 'outputs' is noted here and discussed more fully in 3.3. *Efficiency in relation to outputs* as well as in *4. Is efficiency sufficient? Distilling the criticisms*.

3.2.a. Greenhouse gas emissions

The terrestrial livestock sector accounts for 14.5% of global GHG emissions. Overall emissions from aquaculture and capture fisheries remain unquantified. While likely to be considerably lower in aggregate they can be significant, on a per kg basis, for particular aquatic species. For both terrestrial and aquatic systems emissions vary widely not only between species, but also between the same species in different systems, and indeed between the same species in the same systems under different management regimes. Very broadly speaking, carbon intensities are highest in very extensive ruminant systems and lowest in herbivorous fish species; certain forms of mollusc production generate the fewest emissions of all. (see box 4)

The two dominant changes taking place within the terrestrial livestock sector – the shift from ruminant to monogastric production, and towards greater intensification/specialisation – have important implications for emissions and emissions intensity. Poultry meat and eggs have a lower carbon footprint per unit of food output than any other terrestrial animal product, although emissions for some aquatic animals are higher (see box 3.2.a. *Greenhouse gas emissions* above). And animals reared in more specialised and more intensive systems have a relatively lower carbon footprint than

BOX 4: Climate impact from animal products

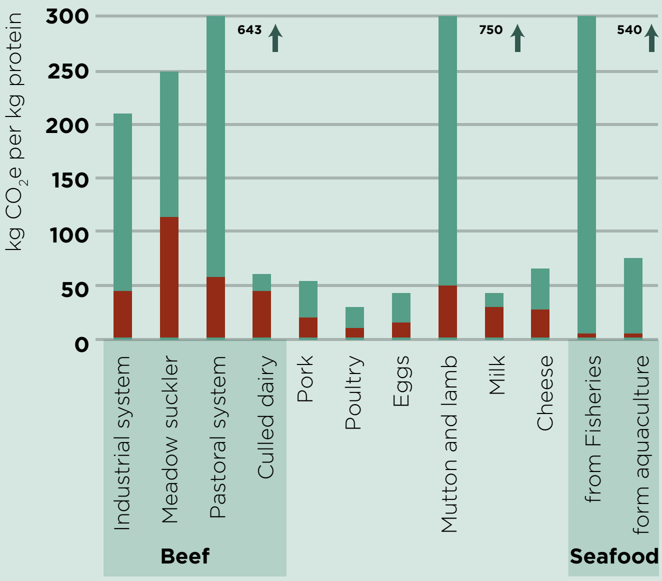
The climate impact from different animal products shows great variation (Figure 2). Emissions from ruminant meat production are generally greater than from monogastric species because methane is emitted during enteric fermentation and feed conversion ratios are higher. Variation within ruminant production systems are also large, reflecting differing extensities in production. Animals in intensive systems gain weight more quickly and are generally slaughtered at an earlier age. Therefore less methane is produced overall, and less feed consumed per kg of body weight gain, the consequence being a lower carbon footprint. Production systems for pork, poultry, egg and dairy are more homogenous and emission ranges hence smaller.

The impacts of a given livestock type or system also depend on the system boundaries and how impacts are allocated.[66] For example the climate impact from beef meat from culled dairy cows is often calculated as lower since a proportion of the emissions are allocated to the milk produced; on a per animal basis of course, the overall impact per animal will be the sum of those two parts. Note that most LCA studies also calculate emissions at the herd level, and so take account of unproductive animals and mortalities.

The climate impact of wild fisheries varies greatly, reflecting differences in the amount of energy used to fuel fishing boats per kg of landed edible fish. Emissions range from the lowest carbon impact per kg protein of all animal products up to among the highest for lobster trawling which is highly energy intensive. The range in emissions from aquaculture reflects differences in feed conversion ratios as well as differences in the type and amount of energy used to produce feed and power the aquaculture systems.

Carcass utilisation also influences the carbon efficiency calculation. The more flesh obtained, the fewer animals are needed for a given quantity of edible product. Typical values for the edible meat/fish as percentage of the live animal weight are: beef meat 37%; pork and chicken 56%, salmon up to 70% and tilapia 35%. How well a carcass is utilised depends on the species in question and human preferences as discussed in Box 1: *Edible efficiency of different animal species and parts* above. There are also non-food outputs that can be obtained from the carcass or livestock system, and a proportion of the emissions can therefore be allocated to these.[67] How and how much of the impact should be allocated to food versus non-food products or services depends on the purpose and design of the analysis and ideas about need.

Figure 2: Climate impact from the production of animal products as found in published LCA



Red columns show lowest value and Green columns show variation interval. Data from Nijdam *et al* (2012).[68]

[66] Flysjö A, Cederberg C, Henriksson M, Ledgard S. (2011). How does co-product handling affect the carbon footprint of milk? Case study of milk production in New Zealand and Sweden. *The International Journal of Life Cycle Assessment*, 16(5): p. 420-430.

Flysjö A, Cederberg C, Henriksson M, Ledgard S. (2012). The interaction between milk and beef production and emissions from land use change e critical considerations in life cycle assessment and carbon footprint studies of milk. *Journal of Cleaner Production*, 28: p. 134-142.

Henriksson P, Guinée J B, Kleijn R, de Snoo G, (2012) Life cycle assessment of aquaculture systems—a review of methodologies. *The International Journal of Life Cycle Assessment*, 17(3): p. 304-313.

[67] Weiler V, Udo HMJ, Viets T, Crane TA, De Boer IJM, (2014). Handling multi-functionality of livestock in a life cycle assessment: the case of smallholder dairying in Kenya. *Current Opinion in Environmental Sustainability*, 8: p. 29-38.

[68] Nijdam, D., T. Rood, and H. Westhoek, (2012). The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. *Food Policy*, 37(6): p. 760-770

their extensive counterparts, as numerous life cycle assessments have shown.[69] This is because breeding, feeding and housing regimes optimise the feed conversion process such that less feed is needed to produce a given quantity of meat output than in more extensive systems. Since emissions arise from the embedded emissions in food production and from the animal's own metabolic processes, the more efficiently these operate the lower the emissions.

In short, the conclusions derived from life cycle assessments concur with, and follow the same logic as, thinking about feed conversion efficiency: monogastrics are more GHG efficient than ruminants, and intensively reared animals (of all types) more so than their extensively reared counterparts.

Critics of these LCA-derived conclusions tend to argue that this carbon efficiency is underpinned by the 'inefficiency' of feeding grains to livestock – in other words they challenge the validity of the inputs to the process, as discussed in 3.1. *Efficiency in relation to inputs* above. Failure to account for carbon sequestration in grasslands may also be highlighted; studies that do include this carbon sink do show more favourable results for more extensive systems.[70] How emissions from deforestation are allocated can also change the picture; if the increase in soy demand is seen as the main driver of deforestation and emissions from deforestation therefore allocated to soy production this will raise the carbon footprint of the intensively reared animals.[71] (Note that the both these are highly challenging to calculate and associated with considerable uncertainties.[72])

Some critics go further, and make points that are currently unsupported within the mainstream scientific community. For example they may advocate management approaches such as the 'holistic grazing' methods of Allan Savory where it is claimed that huge quantities of carbon can be sequestered; here ruminant grazing is transformed from problem into solution. A related criticism is the view that methane is somehow a 'natural' gas and that a baseline methane count for wild ruminants which have been replaced by farm animals needs to be taken into account.[73] By contrast, it is carbon dioxide, arising from fossil energy use in industrial crop and 'landless' intensive livestock production that is the real cause for concern. The problem lies in the system of production, rather than in the numbers of livestock reared.

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69 Nguyen, T.L.T., Hermansen, J.E., Mogensen, L., (2010). Environmental consequences of different beef production systems in the EU. J. Clean. Prod. 18,756–766.

Pelletier, N., Pirog, R., Rasmussen, R., (2010). Comparative life cycle environmental impacts of three beef production strategies in the Upper Midwestern United States. *Agricult. Syst*. 103, 380–389.

Peters, G., Rowley, H., Wiedemann, S., Tucker, R., Short, M.D., Schulz, M., (2010). Red meat production in Australia: life cycle assessment and comparison with over-seas studies. *Environ. Sci. Technol.* 44, 1327–1332.

70 Halberg N, Hermansen J, Sillebak Kristensen I, Eriksen J, Tvedegaard N, Molt Petersen B (2010) Impact of organic pig production systems on CO2 emission, C sequestration and nitrate pollution. Agron. *Sustain. Dev*. 30 721–731

71 Leip A, Weiss F, Wassenaar T, Perez I, Fellmann T, Loudjani P, Tubiello F, Grandgirard D, Monni S, Biala K, (2010). Evaluation of the Livestock Sector's Contribution to the EU Greenhouse Gas Emissions (GGELS). Final Report. European Commission, Joint Research Centre.

72 Röös E and Nylinder, J (2013) Carbon footprint of meat production – variations and uncertainties. Report 2013:063. Department of Energy and Technology, SLU, Uppsala. http://pub.epsilon.slu.se/10766/

73 Wahlquist, A.,(2012), Cattle and methane: More complicated than first meets the (rib) eye, Shaping tomorrow's world, Available at: http://www.shapingtomorrowsworld.org/wahlquistmethane.html

Finally, these critics point out that LCAs are, usually and to date, based on just one functional unit – food output – however measured (weight, energy value, protein and so forth), and fail to account for the multifunctionality of livestock systems and the differences in useful output yielded by different systems. These outputs will include manure but also livelihoods, leather, traction, the maintenance of landscapes and aesthetic values as well as ethical 'goods' such as animal welfare. Section 3.3. *Efficiency in relation to outputs* discusses these issues in more detail. Looking more narrowly at nutrition there may be differences in the quality of meat produced in different systems (grain- versus grass-fed beef, free range versus intensively reared chickens) as well as more broadly the differing roles of livestock foods in different systems and under different dietary scenarios. For example it has been argued that if we confined our consumption of meat and milk only to the amount obtained from rearing animals on byproducts and rough grazing land then the overall quantities consumed would be fairly low; their nutritional value would be positive and their environmental impacts relatively benign.[74]

As can be seen, some of these criticisms are based on uncertainties in our knowledge (as in the case of soil carbon sequestration), others on differences in how the purpose of animal production is defined (to meet food demand, to provide adequate nutrition or to additionally provide non food outputs); and other criticisms still are based on how GHG are weighted against other environmental considerations such as the quality of feed use, or the different 'qualities' or naturalnesses of the various GHGs emitted.

3.2.b. Nutrient losses

Nutrient use efficiency is a much used concept. Discussed particularly in regard to nitrogen and phosphorus , the relationship – as in the case of feed conversion, and carbon efficiencies – between the nutrient outputs from and the inputs to the system is key. Multiple approaches to defining nutrient efficiency have been developed; these vary in the scale of analysis (crop, farm, or food system level), the time frame (single crop season versus a crop or crop-livestock rotation) and the sources they include. For nitrogen, the focus of discussion here, these may include mineral fertiliser, organic manure, biological N fixation or atmospheric deposition.

The particular approach adopted depends too on the goals of the analysis.[75,76] For example a ratio approach (N outputs divided by N inputs) will indicate how efficiently the nitrogen inputted *to* the system is converted into the desired N *from* the system (embedded in protein). A balance approach will consider the difference between inputs and outputs (inputs

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74 Fairlie S. (2010). Meat, a benign extravagence. *Permanent Publications*, UK.

75 Powell, JM, CJP Gourley, CA Rotz, DM Weaverd (2010) Nitrogen use efficiency: A potential performance indicator and policy tool for dairy farms. *Environmental Science & Policy* 13, 217–228.

76 Dobermann, AR (2005): Nitrogen Use Efficiency – State of the Art. Agronomy & Horticulture Faculty Publications. Paper 316. Available at: http://digitalcommons.unl.edu/agronomyfacpub/316.

minus outputs), the aim being to understand what level of overall food output has been obtained (a system may be very efficient, even when very little food is produced) and how much surplus remains in the soil or is lost from the agricultural system. The latter is important in order to assess the potential environmental implications. Efficiency may be high, but if the production intensity is also high, the overall quantity of nitrogen remaining in the soil may nevertheless be problematic.[77] Also necessary to consider is the change in the soil's baseline status. A system can appear to be N efficient in that output relative to input is high – but this efficiency may be achieved by mining the soil for its stored nitrogen over and above the additional N applied – in which case there will be consequences for productivity in the longer term.

How do discussions about nitrogen use efficiency apply to livestock?

Terrestrial livestock systems are both nitrogen-demanding, and inherently leaky. Animals eat plants and to a lesser extent, other animals (fishmeal). The plant feeds animals eat will usually have entailed the extraction of nitrogen from the atmosphere either via mineral fertiliser applications or because nitrogen fixing leguminous plants form part of the feed mix or the cropping cycle; the exception here is when animals are reared on 'unimproved' grasslands.

Only 50-75% of this trapped nitrogen is converted into plant matter – the rest is lost to soils. Once the animals eat these plants, whether grass or grains, further losses arise. Poultry retain around 25% of the nitrogen from feed, converting it into animal flesh, but in some ruminant systems nitrogen retention (as edible N) is as low as 5-10%, with the rest lost as urine or dung.[78] In aquaculture the figure ranges from between 10-60% depending upon the system.[79] The greater the losses, the lower the nutrient use efficiency measured either as outputs/inputs or outputs-inputs. The leakiness of animal systems and thus the inefficiency with which they convert atmospheric nitrogen into the protein N that we eat, is central to environmental criticisms of meat eating.

A second criticism is that the form in which nutrients are lost can have environmental consequences, that differ by livestock system. Taking specialised livestock systems first, the feed used to sustain the livestock will often have been produced in and exported from one region to the receiving unit. This, leads to a concentration of available nutrients on the farm site, in quantities too large for the surrounding land to absorb. Nitrogen point-source pollution, where nutrients leak into soils and waterways or are emitted to air in the form of ammonia, can therefore be a major problem, especially where enterprises are poorly managed. One way of increasing the nutrient efficiency of this system is through the use of anaerobic digestion (AD). The carbon fraction of animal manure is converted into methane (substituting as an energy source for fossil fuels) while the remaining nitrogen-rich digestate can be

[77] EU Nitrogen Expert Panel (2015) Nitrogen Use Efficiency (NUE) – an indicator for the utilization of nitrogen in food systems. Wageningen University, Alterra, PO Box 47, NL-6700 Wageningen, Netherlands.

[78] Leip A., Weiss F., Lesschen J. P., Westhoek H. (2014).,The nitrogen footprint of food products in the European Union. *The Journal of Agricultural Science*, 152, S20–S33.

[79] Edwards, P. (1992). Environmental issues in integrated agriculture-aquaculture and wastewater-fed fish culture systems, p.139-170.In R.S.V. Pullin, H. Rosenthal and J.L. Maclean (eds) Environment and aquaculture in developing countries.ICLARM Conf.Proc. 31, 359p

used as a soil fertiliser. This is the theory; in practice the energy saving benefits of AD need to be weighed against the transport costs of collecting dung from multiple farms.

In extensive grazing systems the impacts will depend on context. Non point pollution can occur, particularly at water sources where livestock may congregate to drink water, in addition to problems such as soil erosion, which also leads to the displacement of nutrients.

It is in traditional mixed crop-livestock systems that differing views on efficiency are perhaps most manifest. Arguably, in such systems, the nutrients that leave the system are not 'lost', but metamorphosed, re-entering in the form of manure which in turn helps fertilise the next generation of plant crops. Livestock help cycle nutrients and avoid the need for synthetic nitrogen. Indeed the role of manure in building soil fertility and quality is central to the principles of organic farming.

However this circularity is only partial. For a start, nearly 40% of all crops grown are used to feed animals, whose dung fertilises the crops, which then feeds the animals – and so forth – with inevitable losses in the form of ammonia, energy and nutrients. This, one might argue, is not so much cyclical as biologically tautologous.

In addition, even in a farm system where all possible wastes are recycled and re-enter the production system, some nitrogen will be lost in the form of exported milk, meat and eggs, as well as to soils and waterways. The loss will have to be replaced if soil fertility is to be maintained. This can be achieved either through the use of synthetic fertiliser or by using additional land to feed the system. As to the latter, this additional 'virtual' land may be embedded in imported feed crops, such as soy. Alternatively, clovers and legumes may be incorporated into crop rotations – so either reducing overall food output or entailing the use of additional farm land to maintain yields. In traditional systems, farm animals may be let out to graze in the daytime and then penned in in the evening. The nutrients in the pastures are retained in the manure which is collected from the enclosures, and applied to the crops. Where land is plentiful, this 'borrowing' of land is not a problem. However in some regions where land is in increasingly short supply, land for feed and nutrient production potentially competes with other uses. Of course in all organic agricultural systems, even livestock-free ones, land dedicated to fertility building is needed, so the same point applies. However overall land requirements in stockless systems will be considerably lower since an entire leaky loop in the nutrient cycle – the animal itself – is omitted.[80]

Within the aquaculture sector, semi-intensive systems can receive N in the form of fertilisers, used to stimulate the growth of algae which fish eat, while N enters intensive systems in the form of fish feed. While many of the issues around nitrogen efficiency will be similar to those of livestock, the impacts of excessive nitrogen use can additionally have a tangible impact on the sector itself because, as noted, water is the living medium. If retained within the aquaculture system, nitrogenous wastes can transform into products (un-ionised ammonia, nitrite and nitrate) that are toxic. At chronic levels this can retard fish growth and if acute can kill them. This is a particular concern in caged systems and intensive ponds; one approach to managing this build up is to let some new water in and old water out but the water leaving the system can pollute the receiving environment.

[80] Tolhurst, I., Stockfree Organic, Stockfree Organic Services, Available at: http://www.stockfreeorganic.net/stockfree-organic/

In contrast recirculating aquaculture systems (RAS) are designed to retain and treat wastes within the system and as such should have much smaller or zero impacts on local receiving waters; biosecurity risks can also be contained. Waste nutrients can be concentrated into sludge and used as a fertiliser. On the other hand, the energy costs of pumping and recirculating culture water through treatment units can be high.

Extensive aquaculture systems – examples include seaweed and mollusc production in coastal areas, and fin and shellfish reared in extensive ponds and lagoons – may be sinks for nutrients rather than net producers and as such can improve water quality.

3.3. Efficiency in relation to outputs

This section considers the outputs from the food system. There are of course many. It begins by exploring the most obvious and widely recognised one, food before going on to consider other outputs that stakeholders may recognise and value differently: animal welfare, social and economic value, and environmental value. As noted in the introduction to 3.2, the distinction between output and impact is somewhat arbitrary – outputs are framed here as those that are considered desirable, in contrast with impacts that are not. However, it is also possible to view the same issue as an impact or an output –negative animal welfare might be an undesirable 'impact' but good welfare a desirable 'output.' Further discussion of this point is found in the conclusions, below.

3.3.a Food and nutrition

Efficiency in relation to nutrition

We rear animals mainly, although not exclusively, because we want to eat them.

Both terrestrial and aquatic animal products are rich in protein. Animal protein is composed of the full range of amino acids needed by humans, in contrast with most plant based foods which usually lack one or more essential amino acids. This said, vegans can readily obtain the full range of amino acids needed provided they consume a range of foods, including grains, pulses, seeds and nuts, over the course of a day. While the protein content of animal products is often the focus of attention, these foods are also rich in readily bioavailable micronutrients. The specific make up will differ by animal type and body part (e.g. muscle versus organ meat), but these include iron, calcium, B vitamins, vitamin A, zinc and essential fatty acids. All these micronutrients can (with the exception of vitamin B12, where fortification is needed) be obtained from purely vegan diets, provided a sufficiently diverse range of foods, in adequate quantities, is consumed.

While meat and dairy products provide these valuable nutrients in abundance, they can also be a rich source of saturated fats and, depending on the form in which they are consumed, calories and salt. Many studies suggest that high meat intakes are associated with negative health outcomes, particularly when it comes to processed and (to a lesser extent) red meat. Association is by no means causation and the associational pathways are varied and in all cases contested.[81] However, the evidence

[81] Garnett T (2014). *What is a sustainable healthy diet? A discussion paper*. Food Climate Research Network – Oxford Martin School – CCAFs

is sufficiently strong for health bodies to recommend limiting intakes of red and processed meat.[82,83] These health associations form the basis for much anti-meat advocacy. It is notable however that studies also find that certain terrestrial animal products such as poultry, dairy and eggs are associated with reduced disease risks – a point on which environmentalists are less vocal.[84,85,86]

As for fish and aquatic products, nutritional advice generally encourages increased consumption since intakes in many high income countries are very low.[87] Within fish types, while all are good sources of protein and various micronutrients, and most types are low in saturated fat, only oily fish are particularly rich in the omega three fatty acids deemed to be protective against heart disease.[88] These include fish from capture fisheries such as mackerel but also farmed fish such as salmon. However, the omega three profile of farmed fish depends on their feeding regime; those fed on soy and fishmeal made from farmed byproducts will have a lower fatty acid composition than those fed on wild fish. And if fish of whatever kind are deep-fried or cooked in a lot of oil, as is often the case, they can be a significant source of calories. This, in many parts of the world can help fuel problems of obesity and associated diseases.

In low income countries the nutritional value of both terrestrial and aquatic products contexts is generally acknowledged,[89,90,91] even by those stakeholders who argue for reduced consumption in the rich world – or at least most of them.[92] The importance of small fish in the diets of poor people has been particularly emphasised by institutions working alleviate poverty through agriculture and aquaculture.[93] These fish can be

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82 Norden (2012). Nordic Nutrition Recommendations 2012 Integrating nutrition and physical activity. Nordic Council of Ministers 2014, Copenhagen, Denmark.

83 SACN (2010). *Iron and health*. Standing Advisory Committee on Nutrition, The Stationery Office. London, UK.

84 Sinha R, Cross A J, Graubard B I, Leitzmann M F and Schatzkin A (2009) Meat Intake and Mortality: A Prospective Study of Over Half a Million People *Arch Intern Med*.;169(6):562-571

85 Pan A, Sun Q, Bernstein A M, Schulze M B, Manson J, Stampfer M J, Willett W C and Hu F B (2012). Red Meat Consumption and Mortality Results From 2 Prospective Cohort Studies, *Arch Intern Med*. doi:10.1001/archinternmed.2011.2287

86 Virtanen, J. K., Mursu, J., Tuomainen, T-P., Virtanen, H., Voutilainen S., (2015). Egg consumption and risk of incident type 2 diabetes in men: the Kuopio Ischaemic Heart Disease Risk Factor Study. American Journal of Clinical Nutrition, DOI: 10.3945/%u200Bajcn.114.104109

87 FAO. (2014). FAOSTAT. Available from http://data.fao.org/ref/262b79ca-279c-4517-93de-ee3b7c7cb553

88 Chowdhury R, Stevens S, Gorman D, Pan A, Warnakula S, Chowdhury S, Ward H, Johnson L, Crowe F, Hue F B and Franco O H (2012). Association between fish consumption, long chain omega 3 fatty acids, and risk of cerebrovascular disease: systematic review and meta-analysis*, BMJ*;345:e6698

89 Dror D K and Allen L H (2011). The importance of milk and other animal-source foods for children in low-income countries *Food & Nutrition Bulletin*, 32, 3, pp. 227-243(17)

90 Long J K, Murphy S P, Weiss R E, Nyerere S, Bwibo N and Neumann C G. (2011). Meat and milk intakes and toddler growth: a comparison feeding intervention of animal-source foods in rural Kenya. *Public Health Nutrition*: 15(6), 1100–1107

91 Neumann, C., Harris, D.M., Rogers, L.M., (2002). Contribution of animal source foods in improving diet quality and function in children in the developing world. *Nutrition Research* 22 (1–2), 193–220.

92 Peta UK, There's Nothing Charitable About Cruelty to Animals, Available at: http://www.peta.org.uk/living/charities-donate-animals/

93 Thilsted, S.H., Wahab, M.A. (2014). Nourishing Bangladesh with micronutrient-rich small fish. CGIAR Research Program on Aquatic Agricultural Systems. Penang, Malaysia. Policy Brief: AAS-2014-08.

eaten whole, bones, head and all; body parts that are especially rich in micronutrients; it is also observed that traditional polycultural systems yield a variety of aquatic products – diversity is an important indicator of nutritional adequacy.[94]

Evolution of metrics for assessing dietary sustainability

A growing body of academic research now focuses on investigating the relationship between good nutrition (encompassing macro and micronutrients) and environmental sustainability at least in relation to GHGs, land or water use; and to assessing the potential for defining dietary patterns that marry nutritional and environmental objectives. Individual studies differ, however, according to the scale of analysis: some focus on individual foods, others on particular dietary patterns (vegetarian, vegan, paleo and so forth), some on optimised diets and others still on real life diets. The scale or focus of analysis influences the conclusion.

At the broadest level are studies that compare current typical (generally Western) diets with defined alternatives that differ in their animal product content. Usually fish consumption is kept unaltered. These defined alternatives may include 'healthy' diets that meet official dietary guidelines, other recommended diets such as the 'Mediterranean,' New Nordic, or 'Harvard Healthy Eating Plan', as well as idealised versions of vegetarian and vegan diets. Generally pulses and soy are specified as meat substitutes. Environmental impacts are assessed; and since diets are idealised, ensuing health benefits are assumed.[95,96,97,98]A variant is to assess not only the environmental impacts but also the nutritional content of these modelled diets. Some consider only macronutrients (calories, fat, protein) and fruit and vegetable intakes,[99,100,101] but with growing recognition that animal products are rich sources of important micronutrients, they increasingly include analysis of these too.[102,103]

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94 Ruel M T (2003). Operationalizing Dietary Diversity: A Review of Measurement Issues and Research Priorities. J. Nutr. 133, 11, 3911S-3926S

95 Vanham D, Hoekstra A Y, Bidoglio G (2013). Potential water saving through changes in European diets, *Environment International* 6145–56

96 Stehfest E, Bouwman L, van Vuuren DP et al. (2009). Climate benefits of changing diet. *Climatic Change*, 95,1-2.

97 Pairotti M B, Cerutti A K, Martini F, Vesce E, Padovan D and Beltramo R (2014). Energy consumption and GHG emission of the Mediterranean diet: a systemic assessment using a hybrid LCA-IO method. *Journal of Cleaner Production* xxx 1e10

98 Saxe H (2014). The New Nordic Diet is an effective tool in environmental protection: it reduces the associated socioeconomic cost of diet, Am J Clin Nutr doi:10.3945/ajcn.113.066746.

99 Van Kernebeek HRJ, Oosting SJ, Feskens EJM, Gerber PJ and De Boer IJM (2014). The effect of nutritional quality on comparing environmental impacts of human diets, *Journal of Cleaner Production* xxx 1e-12

100 Van Dooren C and Kramer G (2012). Food patterns and dietary recommendations in Spain, France and Sweden, Available at: www.livewellforlife.eu

101 WWF UK (2011). Livewell: a balance of healthy and sustainable food choices, WWF UK, Godalming, UK

102 Saxe H (2014). The New Nordic Diet is an effective tool in environmental protection: it reduces the associated socioeconomic cost of diet, *Am J Clin* Nutr doi:10.3945/ajcn.113.066746.

103 Röös, E., Karlsson, K., Witthöft, C., Sundberg, C., (2015). Evaluating the sustainability of diets–combining environmental and nutritional aspects. *Environmental Science & Policy*, 47:157-166. DOI: 10.1016/j.envsci.2014.12.001

A different approach is to start with national nutritional recommendations and adopt a linear optimisation approach to specify how these might be met at less GHG cost (with cuts in the meat content key to the changes modelled), and in ways that are judged to be culturally acceptable.[104,105,106]

A few studies more explicitly define an environmental 'budget' for food.[107,108] This in itself is a normative judgement based on assumptions about emission ceilings and the importance of spending emissions on food rather than on other activities.[109]

A minority of studies are distinctive in that they examine a range of real – rather than idealised – diets. Scarborough et al (2014) and Soret et al (2014) find that the typical diets of vegetarians and vegans generate fewer emissions than that of meat eaters.[110,111] Vieux *et al* (2013) find that 'higher nutritional quality' diets do not generate fewer emissions than lower quality ones, but then the animal product content did not vary substantially across the diets they characterised. [112]

A different approach is to start at the level of the individual food. While many studies point to the high GHG footprint of animal products per 100g or per 100kcal, might one draw a different conclusion if a more nutritionally relevant functional unit were used? Within the field of nutrition various nutrient density indices have been developed; these aggregate different essential nutrients into a single score so that the overall healthfulness of a particular food can be assessed. Foods are 'credited' for their desirable nutrients – vitamins, minerals, protein and so forth – and points deducted for saturated fat and salt. The resultant nutrient density score can then be presented as a ratio to its climate impact. Drewnowski et al find that measured in this way, the climate efficiency of animal products is somewhat but not vastly higher than other foods – the

104 WWF UK (2011). Livewell: a balance of healthy and sustainable food choices, WWF UK, Godalming, UK

105 Van Dooren C and Kramer G (2012). Food patterns and dietary recommendations in Spain, France and Sweden, Available at: www.livewellforlife.eu

106 Green R, Milner J, Dangour AD, Haines A, Chalabi Z, Markandya A, Spadaro J and Wilkinson P (2015). The potential to reduce greenhouse gas emissions in the UK through healthy and realistic dietary change *Climatic Change* DOI 10.1007/s10584-015-1329-y

107 Röös, E., Karlsson, K., Witthöft, C., Sundberg, C., 2015, Evaluating the sustainability of diets–combining environmental and nutritional aspects. *Environmental Science & Policy*, 47:157-166. DOI: 10.1016/j.envsci.2014.12.001

108 Green R, Milner J, Dangour AD, Haines A, Chalabi Z, Markandya A, Spadaro J and Wilkinson P (2015). The potential to reduce greenhouse gas emissions in the UK through healthy and realistic dietary change *Climatic Change* DOI 10.1007/s10584-015-1329-y

109 Green R, Milner J, Dangour AD, Haines A, Chalabi Z, Markandya A, Spadaro J and Wilkinson P (2015). The potential to reduce greenhouse gas emissions in the UK through healthy and realistic dietary change *Climatic Change* DOI 10.1007/s10584-015-1329-y

110 Scarborough P, Mizdrak A, Briggs ADM, Appleby PN, Travis RC, Bradbury KE, and Key TJ (2014). Dietary greenhouse gas emissions of meat-eaters, fish-eaters, vegetarians and vegans in the UK. *Climatic Change*, 125:179-192.

111 Soret S, Mejia A, ,Batech M, Jaceldo-Siegl K, Harwatt H and Sabate J (2014). Climate change mitigation and health effects of varied dietary patterns in real-life settings throughout North America. *Am J Clin Nutr*;100 (suppl):490S–5S

112 Vieux F, Soler L-G, Touazi D and Darmon N (2013). High nutritional quality is not associated with low greenhouse gas emissions in self-selected diets of French adults, *Am J Clin Nutr*; 97: 569–83

environmental villains of the piece are in fact processed vegetables.[113] Smedman *et al*, adopting a similar approach, conclude that milk delivers a better nutritional bang for its climate buck than orange juice and other drinks.[114]

This individual-food based approach has been criticised on multiple fronts.[115,116] For a start it has been argued that a climate-for nutrient density index should 'cap' credits for nutrients at the recommended intake level, since intakes in excess of requirements gives an unfeasibly favourable score (per unit of GHGs), even though the body does not need, and in many cases cannot store these nutrients.[117] Overall though, the main criticism is that the relevant scale of assessment is the overall diet, rather than an individual food or even individual meals.

The conclusions drawn from these analyses reveal much about the ways in which environmental efficiency is defined by various stakeholders – including, notably the academic community.

First, these studies implicitly take as their starting point the assumption that the main function of food is to nourish people. The functional unit of analysis is nutritional adequacy; the task therefore is to understand how this adequacy might be achieved in ways that generate fewer negative impacts than today. Thus food 'output' is defined in these academic studies in terms of *nutritional quality* rather than simply quantity.

Moreover, since no one food can offer all the nutrients we need, if follows that the value of one food exists not only in its own right but in relation to the other foods consumed. Quality is only meaningful at the dietary level. Some foods may certainly be more 'nutrient dense' than others but a diet composed of just one food, however nutrient dense, will be inadequate. Good health is thus seen as an outcome of a dietary pattern rather than a prescription to consume specific nutrients.

Perhaps most fundamentally, by focusing on nutrition as the output of concern, these studies tacitly assume that this is the ultimate goal of food production; or rather that the efficiency of a system is to be judged against its ability to meet human needs. As opposed to human *demands*, that is – our desire for pleasure, or status, or the cultural roles of meat and animal farming tend to receive minimal attention. Since our nutritional needs are arguably finite rather than (as for demands), potentially infinite, the needs based approach implicitly places a cap on consumption at the level of

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113 Drewnowski, A., Rehm C. D., Martin, A., Verger, O. E., Voinnesson, M., Imbert, P., (2015), Energy and nutrient density of foods in relation to their carbon footprint, *Am J Clin Nutr*, ajcn.092486. DOI: 10.3945/ajcn.114.092486

114 Smedman A, Månsson HL and Modin A-K (2010). Nutrient density of beverages in relation to climate impact *Food & Nutrition Research*, 54: 5170

115 Röös, E., Karlsson, K., Witthöft, C., Sundberg, C., (2015), Evaluating the sustainability of diets-combining environmental and nutritional aspects. Environmental Science & Policy, 47:157-166. DOI: 10.1016/j.envsci.2014.12.001

116 Scarborough P and Rayner M. (2010). Nutrient Density to Climate Impact index is an inappropriate system for ranking beverages in order of climate impact per nutritional value. Food & Nutrition Research, [S.l.], 54: 5681

117 Kernebeek, H.R.J. van; Oosting, S.J.; Feskens, E.J.M.; Gerber, P.J.; de Boer, I.J.M. (2014). The effect of nutritional quality on comparing environmental impacts of human diets, *Journal of Cleaner Production* 73, 88e99

nutritional sufficiency. As such it poses a counter to the idea of efficiency as just a ratio, a relationship between numerator and denominator, with no concept of a ceiling.

But for other stakeholders, this nutritionally oriented approach is open to challenge. People eat for many reasons, not least for the pleasure it affords. And people seem particularly to enjoy eating environmentally impactful foods, such as meat. Sufficiency does not suffice.

So, given the huge importance of pleasure in people's lives, and food's role in providing it, should pleasure be seen as a legitimate 'output' from the system? If so should one rank it compared with nutritional needs, environmental imperatives or other outputs such as animal welfare (discussed below)? And who should do the ranking?

Arguably trade offs will need to be made. Something may have to give. Unless of course one were to redefine pleasure; to argue that our enjoyment in eating certain foods is not so much biologically fixed as culturally determined, and therefore malleable. Advocates of 'culture over biology' would say that this is in evidence every time people buy a branded box of cereal in preference to its identical tasting, cheaper unbranded alternative, or bottled water when clean tap water is available almost for free. These choices have nothing to do with biology and everything to do with culture as shaped by the market.

Thus environmentalists not only place less emphasis on the imperative of pleasure as compared with nutritional needs but they also place faith in the idea that, if the context of consumption is altered so as to achieve more pro-environmental outcomes, so too would people's preferences. In other words, the environmental 'efficiency' of diets depends on how one ranks the different functional units and how unambiguous those units are.

3.3.b. Environmental value

In Section 3.2, changes in the environment as a result of TAL production were discussed as 'impacts.' The environmental efficiency of the system was seen in terms of the relationship between inputs and environmental impacts – for example surplus nitrogen *out* in relation to nitrogen *in*); or impacts relative to certain outputs – such as CO_2 eq / kg meat, or per unit of calories or protein obtained.

Whichever way the ratio is constructed, the mainstream understanding of environmental efficiency effectively assigns the environment to the 'impacts' category. Changes to the environment are consequences arising from the goal of agricultural production – to produce food.

But if a particular environmental state or quality (such as sustainability or resilience – both general terms that need defining) is classed as an output in its own right, then the perspective shifts in important ways.

Differences in whether changes to the environment are seen as impacts or an output lie at the heart of the controversy around sustainable intensification, a concept that overlaps with environmental efficiency. The grammar of this phrase suggests that intensification, as the noun, is the goal; "sustainable" describes the manner in which it should be achieved. One obvious inference is that intensification as the noun trumps a mere adjective.

The phrasal structure also begs the question: 'intensification of what?' It been argued that one goal should be the intensification of environmental goods.[118,119] However the meanings historically associated with intensification (generally food yields), the historically negative welfare consequences arising from intensification in the livestock sector, not to mention the semantic load that English grammar places on the second word all make it hard for the environmental movement to believe that sustainable intensification will safeguard environmental non negotiables. Note that 'environmental efficiency' has the same adjective noun construction.

But what if the phrase is inverted to 'intensive sustainability'? Sustainability is now the noun and carries the weight of the sentence, while the adjective 'intensive' denotes its vigorous pursuit. Of course, this inversion does not in itself address what we mean by sustainability (does the concept incorporate only environmental dimensions? Surely sustainability must encompass the idea that people are fed adequately?) or what is meant by intensive. But by inverting the phrase it not only puts sustainability first, but it also removes relativity from the phrase. Intensification is potentially infinite; sustainability, rightly or wrongly, suggests a state, even if the relationships among the influences on that state fluctuate.

The purpose of this grammatical digression is to cast light on the two main reasons why critics mistrust the sustainable intensification concept: because it speaks of relatives rather than absolutes, and because the environment is designated as an impact, rather than desired output in its own right.

But if environmental sustainability is to be viewed as a legitimate output in its own right, then a method of valuing it needs to be agreed. This is where accountancy tools such as payments for ecosystem service (PES) or natural capital valuation are suggested.

Putting a price on the goods and services that nature provides – climate regulation, water filtration and so forth – is a way of ensuring that nature, or rather an unpolluted, unperturbed nature, is validated as an output in its own right. But the concept is highly contested (and counter contested) on practical and ethical grounds.[120] Some argue that the approach simply perpetuates today's exploitative neoliberal capitalist ideology that caused the environmental damage we witness.[121,122] Even those who see a role for

118 Garnett T and Godfray C (2012). Sustainable intensification in agriculture. Navigating a course through competing food system priorities, Food Climate Research Network and the Oxford Martin Programme on the Future of Food, University of Oxford, UK

119 Garnett T, Appleby M C, Balmford A, Bateman I J, Benton T G, Bloomer P, Burlingame B, Dawkins M, Dolan L, Fraser D, Herrero M, Hoffman I, Smith P, Thornton P K, Toulmin C, Vermeulen S J and Godfray H C J (2013). Sustainable Intensification in Agriculture: Premises and Policies, *Science*, 34, 6141, 33-34

120 Schröter M, van der Zanden E H, van Oudenhoven A PE, Remme R P, Serna-Chavez H M, de Groot R S and Opdam P (2014). Ecosystem Services as a Contested Concept: a Synthesis of Critique and Counter-Arguments. *Conservation Letters*, 7, 6, 514–523

121 Monbiot, G., (2012), Putting a price on the rivers and rain diminishes us all, the Guardian, Available at: http://www.theguardian.com/commentisfree/2012/aug/06/price-rivers-rain-greatest-privatisation

122 Kosoy N and Corbera E (2010). Payments for ecosystem services as commodity fetishism. *Ecological Economics* 69 1228–1236

PES schemes are open-eyed about the many challenges implementation presents.[123,124] Easy answers are not available, but what is clear is that both critics and advocates of PES type approaches are united in their desire to make the environment visible and of weight in itself, as an *output*.

3.3.c. Animal welfare

Animal welfare as an output from the system?

Critics of the mainstream efficiency approach argue that efficiency as a proxy for *environmental* sustainability is not only limited for all the reasons discussed, but that the ongoing shift to intensification also has damaging consequences for animals' wellbeing.[125] And good animal welfare is an ethical 'non negotiable', a moral boundary condition which food system activities need to respect , much as environmentalists may talk about planetary boundaries. Indeed for these groups, a definition of sustainability that does not incorporate this socio-ethical dimension is incomplete.

Thus, whereas from a mainstream efficiency perspective negative welfare is an impact, a potentially necessary price we have to pay for a particular definition of environmentally efficient food, for the animal ethics community good welfare is an output – a legitimate goal in itself.

The risks to welfare arising from intensification can be mitigated somewhat by managerial improvements (which can also increase productivity). One can also choose to adopt a particular definition of good welfare that is more in keeping with the sorts of goods that well managed intensive systems can provide (see below). Ultimately, however, the discussion is often framed as a matter of trade offs – good welfare *versus* environmental efficiency *versus* demand *versus* commercial considerations. The language of trade offs suggests that issues are separate and that goals can be ranked. And so in developed countries, even though the need for 'good welfare' is generally accepted by government, mainstream consumers and the food industry, other considerations such as the cost of production or the price in store, may (beyond the legal welfare minimum) often be prioritised.

However for welfare advocates, welfare is a goal in itself, on a par with good human nutrition and an improved environment. If a 'price' is to be paid, then that price is our demand for high intensity foods – although eating less meat may not in fact be seen as a cost, but as a benefit. By moderating demand, good welfare, an improved environment and adequate nutrition can be achieved. Of course, leaving aside management considerations, advocates also argue that the ensuing reduction in overall livestock numbers would also improve animal welfare since fewer farm animals overall would be born to suffer.

123 Costanza, R., de Groot, R., Suttonc, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., Farber, S., Turner, R. K. (2014), Changes in the global value of ecosystem services, *Global Environmental Change* 26 152–158

124 Editorial (2009). Payment for Ecosystem Services and the Challenge of Saving Nature. *Conservation Biology*, 23, 4

125 Shields, S., Orme-Evans, G., (2015). The Impacts of Climate Change Mitigation Strategies on Animal Welfare, *Animals*, 5, 361-394; doi:10.3390/ani5020361

Once again, ideas about demand, the inevitability of increases in demand, and the importance of catering to demand as opposed to needs or other desired goals, sit at the heart of this debate.

But if animal welfare is a legitimate output, then what is it and how it is to be measured? The metric selected will be the functional unit against which its relationship with efficiency is assessed.

What is good welfare? And how is it measured?

The rearing of livestock is the subject of considerable scrutiny by animal ethicists and activists. At one, the most extreme level, all definitions of 'good welfare' are unacceptable: this is the view of animal rights advocates who condemn any use of animals for human purposes as exploitation and who therefore espouse veganism (Singer 1975, Gary Francione, PETA, undated).[126,127,128]

Those who accept that animals can or will inevitably be used for human purposes focus on improving their welfare. The highly influential 'five freedoms' which developed from the UK's 1965 report into the welfare of intensively reared livestock[129] define some broad principles of care. Animals should be free from: hunger and thirst; discomfort; pain, injury or disease; and fear and distress. They should also be free to express natural behaviour, and should have sufficient space, proper facilities and company of the animal's own kind in order to enable them to do so (FAWC 2009).[130] It is this last freedom that is the most contested. Ultimately, this definition encompasses two ideas, encapsulated in a definition of welfare offered elsewhere, that animals should be 'fit and happy.'[131] These form the basis of thinking about welfare in the West.

These are the principles: how does one measure progress towards or against these goals? Much animal behaviour and welfare research seeks to develop metrics to assess animals' welfare and so identify how to improve it.[132] Studies generally adopt one or a combination of three approaches.

Some focus on assessing the physiological status of animals – their health. Measures of wellbeing can include their growth and productivity, longevity, absence of disease, fertility as well as measurements of stress or heart rate.

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[126] Singer, P. (1975). Animal Liberation, Harper Collins

[127] Peta, Available at: http://www.peta.org/

[128] Animals As Persons: Essays on the Abolition of Animal Exploitation (2008). *Columbia University Press*, ISBN 978-0-231-13950-2

[129] HMSO (1965). Report of the Technical Committee to Enquire into the Welfare of Animals kept under Intensive Livestock Husbandry Systems, the Brambell Report, *HMSO London*, ISBN 0 10 850286 4.

[130] FAWC (2009) Farm Animal Welfare in Great Britain: Past, Present and Future, Farm Animal Welfare Council, UK. Available at: https://www.gov.uk/government/publications/fawc-report-on-farm-animal-welfare-in-great-britain-past-present-and-future

[131] Webster J (2005). Animal Welfare: Limping Towards Eden, Wiley-Blackwell

[132] Welfare Quality – Science and society improving animal welfare, Available at: http://www.welfarequality.net/everyone/41858/5/0/22

A second approach is to look at animals 'affective state' – their feelings and emotions – as 'expressed' through their behaviours. Efforts here are directed at assessing what animals actively want or seek to avoid by examining their motivations, through choice and other experiments.[133]

The third is not so much a research approach as a mindset, and is explored most fully in the literature on animal ethics. It is founded on the contested notion of 'naturalness;' the idea that a natural environment is essential if animals are to be 'happy'. Arguments that naturalness is a condition of good welfare may link to the first two definitions of good welfare (that a natural environment is more conducive to good health, or that cows 'want' to be outdoors) but arguments in favour of naturalness go beyond this. There is a presumption that naturalness is good of itself – it has intrinsic value, beyond any animal welfare benefits that it fosters.[134] Interestingly, the general public, at least in the West – whose own urbanised living environment is definitively 'unnatural' – place great value on 'naturalness' in their understanding of good welfare, even though their understanding of the issues may be minimal.

While the debate about animal welfare in terrestrial systems may be vigorous, fish welfare tends to be a minority interest for the general public[135] even though fish are capable of pain and distress[136] and notwithstanding the efforts of animal welfare NGOs.[137,138] This said, the UK salmon industry has made significant progress in establishing and observing high standards of animal welfare, driven by the recognition that high standards can yield productivity and economic g benefits.[139] Note that there will be important differences between aquatic species – more so than in the terrestrial sector. While squid and fish may be capable of pain, this is unlikely to be the case for species such as mussels and oysters that lack a central nervous systems and as such welfare issues in their production will be minimal.

Measuring animal welfare in relation to efficiency

The different ways of measuring welfare allow stakeholders to place greater emphasis on one approach over another, leading to disagreements about the relationship between animal welfare and environmental efficiency.

133 BBSRC Animal Welfare Initiative, accessed from website May 2007, Available at: http://www.vetschool.bris.ac.uk/bbsrc/page_01.html

134 Musschengeer A W (2002). Naturalness: Beyond Animal Welfare, *Journal of Agricultural and Environmental Ethics*, Volume 15, Number 2

135 Animal welfare in modern production systems for fish, Available at: http://www.slu.se/en/departments/animal-environment-health/research/research-project/animal-welfare-in-modern-production-systems-for-fish/

136 Braithwaite VA and Huntingford FA (2004). Fish and welfare: do fish have the capacity for pain perception and suffering? *Animal Welfare* 13, S 1, 87-92(6)

137 CIWF, Fish – the forgotten farm animal, Available at: http://www.ciwf.org.uk/our-campaigns/fish-farming/

138 RSPCA, Farmed fish, Available at: http://www.rspca.org.uk/adviceandwelfare/farm/fish

139 Freedom food, Why good welfare is good business, Available at: http://industry.freedomfood.co.uk/industrynews/2013/04/why-good-welfare-is-good-business-for-salmon

Animal welfare advocates argue that efforts to improve the environmental efficiency of production through intensification undermine both the ‘fit’ and ‘happy’ side of the welfare since animals are forced to live in an unnatural environment. As regards health or fitness, intensive terrestrial systems, underpinned by intensive breeding programmes, ‘unnatural’ feeding regimes and poor husbandry, generate physiological problems such as mastitis in cows and bone fractures in chickens. In capture fisheries there are concerns about inhumane capture and slaughter and in aquaculture around physical injuries, skeletal deformities, disease transmission, poor handling and slaughter methods.

As to happiness, confined conditions usually mean that animals are thwarted in their ability to perform natural behaviours or to live in an environment that approximates to their evolutionary living environment. Migratory farmed fish species are unable to migrate as they have evolved to do.

At a deeper level, for these stakeholders, the concept of efficiency as applied to sentient creatures is fundamentally abhorrent because it reduces animals to units of production, items for processing. The logical conclusion of this mindset is veganism since the end point in any system, however good the welfare, is slaughter, and the dismembering of once sentient bodies into marketable products. However, for those less absolutist in their thinking, more natural systems are seen to offer a middle way in that the integrity of animals as sentient beings is respected at least while they live.

By contrast a mainstream environmental efficiency perspective may see measures to improve the health of animals as compatible with its ‘more with less’ approach. Healthy animals are more productive and more fertile. Well managed intensive systems can in fact deliver excellent health since specialist veterinary care may be available, as well as welfare enhancing technologies such as robotic milking. It is often pointed out that good and bad welfare occurs in all systems, and indeed that mortality levels and some health problems such as parasite infections, are often higher in free range systems. Less emphasis is placed on the ‘naturalness’ aspect of good health and the notion is sometimes dismissed as romantic anthropomorphism. Stakeholders may point out that since all farmed animals are destined for slaughter and eventual portioning into edible commodities it is simply disingenuous to suggest that only some systems ‘commoditise’ life; they all do.

In other words, this perspective may view good welfare and environmental efficiency as often synergistic – but at the point where certain aspects of the good welfare definition run counter to intensification, this holistic definition of good welfare, encompassing the idea of naturalness, is either challenged or the importance of animal welfare per se ranked lower than other imperatives, such as the need to sustain demand, or to achieve carbon efficiencies.

To summarise, the animal welfarist critique of mainstream definitions of environmental efficiency is three fold. First welfarists question the adequacy of environmental efficiency as a measure of environmental sustainability in ways that have been discussed above. Second they argue that the definition as it stands sees welfare as an ‘impact’ to be managed rather than a desired ‘output’ in its own right, and as such is inadequate. And third they challenge the idea that sustainability is about making trade-offs. Environmental, health and ethical goals can be aligned if we eat ‘less and better’ meat.[140] This does not necessarily involve a sacrifice in our quality of life since pleasure is so culturally determined – but even if it does, environmental priorities trump human greed.

3.3.d. Social and economic value

In addition to all these charges, the mainstream definition of environmental efficiency is also criticised for ignoring the non-tangible social outputs that arise from apparently less efficient systems. Many people in low income countries keep livestock not only, or not even predominantly, for their meat or milk, but because they help sustain their livelihoods, a word that encompasses but is not synonymous with income or employment, because it also suggests resilience (the spreading of risk) and the ability to take part in the social life of the community.[141]

A growing recognition of the social impacts from the food system is driving the evolving discipline of 'social LCA'.[142] For example, the United Nations Environment Programme has now published guidelines on how to measure the social impacts of food production, distribution and supply on the workers, on local communities, consumers, society and all value chain actors.[143]

Another approach can be found in Weiler *et al* (2014).[144] This study examines how the carbon footprint of smallholder dairying compares with conventional intensive milk production if diverse aspects of livelihoods value are also recognised as outputs – as opposed to measuring the social impacts when the output is purely food. Predictably it finds that if environmental impacts are allocated just to the meat and milk output, smallholder dairying performs poorly compared with intensive dairying. But if emissions are also allocated to outputs such as manure (for fertilising), and to cattle as sources of finance and insurance; or more 'intangibly' still, to farmers' own assessment of the value of cattle in their lives, then the carbon footprint of the milk is similar to that of intensive production systems.

Assigning value to these 'outputs' is of course a value-driven undertaking in that it is necessarily selective and there is always a counterfactual to consider – what, for example, might be the impacts generated by alternative insurance solutions for small-holders? As it stands, traditional livestock systems provide jobs and livelihoods, more so (on a per yield basis) than intensive systems where capital to a large extent replaces labour. However there may also be non food outputs from the intensive food system that could also be quantified, but are not in this study. Moreover, the idea

140 Eating Better, Available at: http://www.eating-better.org/

141 Herrero M, Thornton P K, Gerber P and Reid RS (2009). Livestock, livelihoods and the environment: understanding the trade-offs (Review) *Current Opinion in Environmental Sustainability*, 1, 2, 111-120

142 Paragahawewa U, Blackett P and Small B (2009). Social Life Cycle Analysis (S-LCA): Some Methodological Issues and Potential Application to Cheese Production in New Zealand. Report prepared for AgResearch, New Zealand

143 UNEP (2009) Guidelines for Social Life Cycle Assessment of Products. United Nations Environment Programme, Paris.

144 Weiler V, Udo HMJ, Viets T, Crane TA, De Boer IJM. (2014). Handling multi-functionality of livestock in a life cycle assessment: the case of smallholder dairying in Kenya. *Current Opinion in Environmental Sustainability* 8:29-38

that smallholder farming[145] or even jobs in agriculture[146] are worth preserving and supporting in and of themselves is not universally held. While smallholder agriculture is the main source of livelihoods for poor people in low income countries, it has been argued that the challenge now is to help them transition out of it[147] – whether into other parts of the food sector, by adding 'value' through processing to agricultural commodities, or into other areas of employment.

4. Is efficiency sufficient? Distilling the criticisms

This paper began by observing that environmental efficiency means different things to different people. People define it in diverse ways and have disparate views on whether the concept provides a helpful route to assessing progress towards environmental sustainability, not to mention broader societal sustainability goals. It then took a closer look at these differences manifest themselves in the ways that stakeholders think about and value the inputs to, and the impacts and outputs from the TAL system.

In the course of doing this certain common themes or categories of criticism have emerged and this penultimate section tries to summarise them.

Efficiency is relative

First, the defining characteristic of efficiency is that it is relative – it is the balance of a ratio. Critics point out that there are absolute limits to the amount of environmental damage that can be inflicted upon the environment and so the relativity inherent in the efficiency concept makes it by definition inadequate measure of sustainability. A highly efficient system may still generate a great and ever increasing quantity of negative impacts if the consumption of the outputs increases faster than the efficiency gains. Thus they argue that an absolute limit to that consumption – a cap – needs to be specified, to ensure that we observe the planetary boundaries.

The idea of globally applicable limits or planetary boundaries has been challenged both on technical and ideological fronts.[148,149] Many of the criticisms that were

145 Van Vliet JA, Schut AGT, Reidsma P, Descheemaeker K, Slingerland M, van de Ven GWJ, (2015), Demystifying family farming: Features, diversity and trends across the globe, *Global Food Security*. 1;5(C):11–8.

146 Collier, P and S Dercon (2009), "African Agriculture in 50 years: Smallholders in a Rapidly Changing World?" Expert Paper for the FAO Conference on "How to Feed the World in 2050?", Rome, 12-13 October 2009.

147 Dorward, A, Anderson, S. Nava, Y. Pattison, J., Paz, R., Rushton, J. and Sanchez Vera, E. (2009) Hanging In, Stepping up and Stepping Out: Livelihood Aspirations and Strategies of the Poor, *Development in Practice*, 19 (2). 240-247.

148 Blomqvist L, Nordhaus T, and Shellenberger M (2012). The planetary boundaries hypothesis: A review of the evidence. *The Breakthrough Institute*, Oakland, CA. USA.

149 Revkin, A.C., (2015) Can Humanity's 'Great Acceleration' Be Managed and, If So, How? Available at: http://dotearth.blogs.nytimes.com/2015/01/15/can-humanitys-great-acceleration-be-managed-and-if-so-how/?_r=0

prompted by the first planetary boundaries paper[150] have been taken on board and are addressed in the 2015 update[151] and there is now growing (although not universal[152]) consensus that the concept is useful. But even if one accepts the boundaries concept in principle, our values intermesh with our scientific understanding and influence our views on where they should be set. As the authors point out, boundaries are not cartoon barriers whose rupturing tips us into a new reality, but are porous 'zones' of some thickness. As such there is uncertainty, and different people have different attitudes towards risk.

What is more, what or who is the boundary for? Is it a boundary which marks the dangerous point beyond which our human existence may be threatened, or a more biocentric boundary? To take biodiversity as an example, metrics can be and are being developed to ascertain the point at which losses impact upon human societies and functioning – for example where biodiversity loss can jeopardise our ability to produce food, or chemicals, or may exacerbate the broaching of other planetary boundaries.[153] But for some stakeholders the diversity and abundance and uniqueness of living things has value over and above its utility to us. Moreover, even taking a human-centric approach, its value to us is not simply practical but also moral. Its loss diminishes us as moral beings. If one adopts this perspective, we may well have already crossed that boundary.

Then there is human ingenuity to consider. Humans have a habit of pulling techno-rabbits out of hats. We may have a limited 'space' available to live within, but technology may, Tardis-like, modify this space such that it looks bigger on the inside than the out. Calculations based upon assumptions about current trends in technological progress indicate that we cannot achieve deep absolute cuts in livestock related emissions unless we tackle demand. But we may find a way of modifying the rumens of cows and sheep, or of trapping enteric methane, or of developing virtually landless forms of animal feed – or arrive upon some as yet unenvisaged solution. In which case we will be able to continue having our steak and eating it. The question is, should we? This raises the question of what we want for the food system, and how people differ in that regard, a point discussed further below.

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150 Rockstrom, J., W. Steffen, K. Noone, A. Persson, F. S. Chapin, III, E. Lambin, T. M. Lenton, M. Scheffer, C. Folke, H. Schellnhuber, B. Nykvist, C. A. De Wit, T. Hughes, S. van der Leeuw, H. Rodhe, S. Sorlin, P. K. Snyder, R. Costanza, U. Svedin, M. Falkenmark, L. Karlberg, R. W. Corell, V. J. Fabry, J. Hansen, B. Walker, D. Liverman, K. Richardson, P. Crutzen, and J. Foley. (2009). Planetary boundaries:exploring the safe operating space for humanity. *Ecology and Society* 14(2): 32.

151 Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., & Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science* 347(6223)

152 Revkin, A.C., (2015) Can Humanity's 'Great Acceleration' Be Managed and, If So, How? Available at: http://dotearth.blogs.nytimes.com/2015/01/15/can-humanitys-great-acceleration-be-managed-and-if-so-how/?_r=0

153 Mace GM, Reyers B, Alkemade R, Biggs R, Chapin FS, Cornell SE, Dıaz S, Jennings S, Leadley P, Mumbyl PJ, Purvism A, Scholes RJ, Seddon AWR, Solan M, Steffen W and Woodward G. (2014). Approaches to defining a planetary boundary for biodiversity. *Global Environmental Change.* 28:289-297.

All inputs (impacts and outputs) are not equal

There may be differences in how acceptable or legitimate these are or in how they are defined. For example, as discussed, there are different views as to the acceptability of synthetic fertiliser versus biological nitrogen sources. And there are counterfactuals to consider. For example, one might argue that however efficiently a given input is used (land, say) this use is inherently inefficient if it has an alternative and to arguably preferable use.

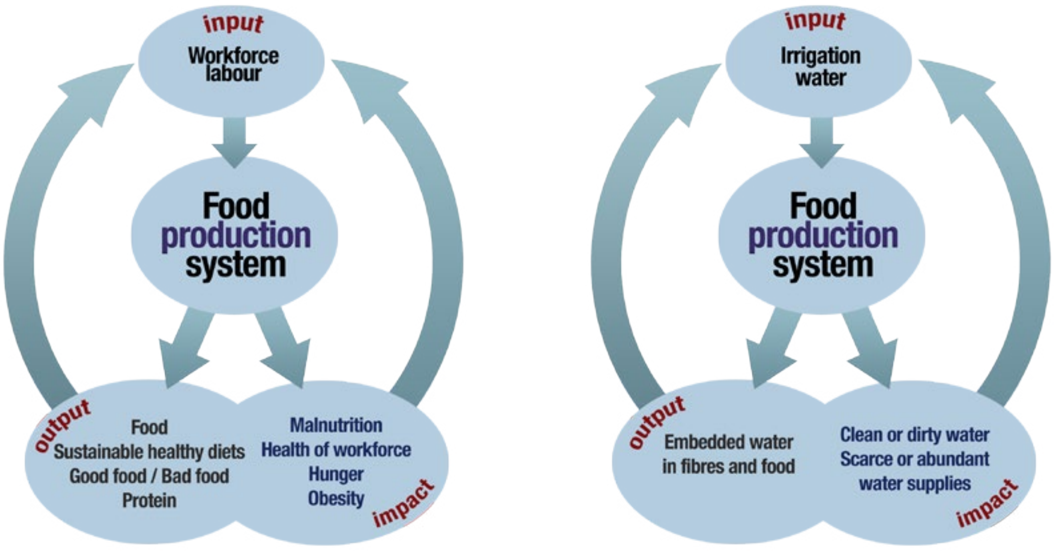
Means, ends and consequences overlap

What is an input, what is an output and what is an impact? We began this paper by arguing that stakeholder differ in how they think about the inputs to, outputs from and impacts of livestock production and consumption. But what clearly emerges over the course of the discussion is that differences are more structural than this. Disagreements arise because there is inherent multivalence among inputs, outputs and inputs. Take, for example, the general concept of 'the environment.' Food production has *impacts* upon the environment since the process uses and may degrade land, emits greenhouse gases and so forth. However, good environmental quality is also for many stakeholders a desired *output* that can come from the system (i.e. intensive sustainability). And finally, the environment is the ultimate *input* to the food production process – for example it is the source of genetic resources, land and water. Table 2 and figure 3 attempt to illustrate this porosity, showing that impacts can also be viewed as outputs, and can also affect the inputs to the system.

Table 3: Food system Inputs, outputs and impacts: a porous relationship

Inputs	Outputs	Impacts
Work force – labour	Food 'More' food (kg, calories) Nutritious foods (macro & micronutrients) Sustainable healthy diets Health for present & future generations	Impacts on: hunger, obesity, malnutrition Health legacy for future generations
Human & institutional knowledge Financial investment Infrastructure	Profit Jobs Livelihoods	Impacts on: the local and global economy; employment; livelihoods; human skills & knowledge
Pesticides & herbicides Fossil fuels & machinery Seeds & livestock breeds Synthetic fertilisers Organic matter – e.g. Cover crops, crop residues, manures & composts Irrigation water Natural capital Land	Resilient ecosystem services Nutrient recycling Fibres & fuels Traction	Impacts on: soil and water quality; land availability; climate (e.g. GHG emissions); water availability; on- & off-farm biodiversity; landscapes; system resilience
Healthy animals	Acceptable animal welfare	Impacts on: animal welfare; our ethical compass

Figure 3 Means, ends and consequences overlap



Of course a concept such as 'the environment' is extremely general and as such can mean all things to all people. But this observation does not explain away the point – it *is* the point. The problem of efficiency is that it begs the question: efficiency of what? For what? With what?

What are the desired outputs?

Ultimately the disagreement among different stakeholders is about goals for the food system. Critics of environmental efficiency assume that what its advocates really want is more food, to meet growing demand and/or to drive agricultural GDP and generate greater profits for the food industry. For these critics, drawn from the environmental, animal welfare and food justice movements, the ultimate goal is a food system based on a different system of production and consumption. For some it may encompass smaller-scale production, using non-fossil fuel based inputs, and producing a diverse range of foods to local markets; one where power is not concentrated in the hands of a few corporations. Others may emphasis the need for plant based diets; others still will call for all of these changes. Ultimately while the details and emphasis may vary, all these stakeholders believe that human demand trajectories must be circumscribed by the requirements of environmental limits.

For an advocate of mainstream efficiency, achieving multiple goals may not all be possible; as such these are to be traded off against one another: efficient livestock production for example, versus free-range extensive. But for a critic of this mainstream approach, the whole discourse on trade-offs is a cul de sac because it is based on a misguided view of what the ultimate goals are – the need for 'more.' If demand is curbed or trends moderated (and this is seen as positive in itself), then the overall output requirement will be lower and high welfare, low-intensity production becomes possible. The discourse is thus about optimising among many goals, rather than maximising one or two at the expense of others, a different framing that indicates a very different vision of what 'good' actually is.

Efficiency is greedy

Critics of efficiency fear the moral implications of an approach that suggests no limits to growth or, as they see it, to human greed.

Efficiency enables two chickens to be produced at the same environmental and economic cost as one; but it also allows us to eat three chickens where we may only have eaten one before. And Jevon's Paradox holds true. So for example, while greenhouse gas emission per kg of chicken produced in Sweden fell by a remarkable 22% between 1990 and 2005, consumption increased by 180% during the same period, making total emissions increase by 150%.[154] Emissions and consumption of other meats followed the same pattern.

Efficient production, among other things, enabled meat to be produced more cheaply, and the economic laws of supply and demand did the rest. Thus the efficiency treadmill, it is argued, requires us to run ever faster running just to stay still.

Efficiency is reductive and – linked to this – lacks resilience

This is an important and often voiced charge against the concept of efficiency. There are many layers to this criticism.

At the most simple, the notion of environmental efficiency is criticised as reductive because the metrics used tend to be simple and single – kg CO2eq/kg meat, for example. Such an approach fails to recognise the multiple outputs that might arise from a production system and as such may lead to the conclusion that intensive systems are more efficient than extensive or pastoral systems.

In line with this view, a growing number of researchers are developing ways of accounting for the non-meat outputs from, for example, pastoral systems as discussed in 3.3.d. *Social and economic value* above. Efforts to quantify the value of nature to humanity through ecosystem services accounting provide another example.

In all cases one may disagree with the choice of outputs included in the analysis and the allocation method used, but arguably much more can be done, methodologically speaking, in this vein. A more difficult challenge for the LCA community is to account for linkages among different inputs, outputs and impacts and also across these categories, and to deal with the fact that impacts can also be outputs or inputs, as discussed above and illustrated in Figure 3 above. Ultimately however, the problem here is less to do with the accounting approach (which will inevitably become more sophisticated) but with the extent to which those in power – the food industry and decision makers – use multi-component measures of sustainability in preference to simple metrics such as tonnes CO_2eq/tonne meat. Thus the charge that the environmental efficiency concept is reductive is (at this level) not so much a criticism of the ratio approach as an accusation that the concept is used in reductive ways.

[154] Cederberg, C., Sonesson, U., Henriksson, M., Sund, V., & Davis, J. (2009). Greenhouse Gas Emissions from Swedish Production of Meat, Milk and Eggs: 1990 and 2005. Gothenburg, Sweden: The Swedish Institute for Food and Biotechnology.

Another angle of criticism is that because efficiency is based on reductive thinking, the outcome is a system that lacks resilience. The word resilience has been applied liberally in recent years to both ecological and socio-economic systems.[155,156] As such it risks going the same woolly way as sustainability, but it adds something to the discussion in that it suggests 'bounce-backability.' It connotes a sense that by spreading risks and keeping various eggs in various baskets, a system is more able to recover from shocks, be that a disease outbreak, climatic event or change in food prices. Resilient systems are complex and – importantly – they see the human and ecological domains as interlinked.[157] A resilient system, moreover, explicitly accepts a certain level of slack, or redundancy in the system; it keeps the cupboard stocked in case of emergencies.[158]

An efficient system on the other hand strives to avoid redundancy, operating as it does on a 'lean manufacturing' principle. This makes it vulnerable, it is argued, to environmental, economic or societal shocks: for example intensive monocultural systems risk being brought down by a pest attack or a fluctuation in the global commodity market.

From a mainstream efficiency standpoint, one may accept the need for resilience but argue that it can obtain at different scales; it is not necessary, for example, for every field to be polycultural. Moreover the need for resilience suggests we should invest more in crop breeding, including via genetic modification – approaches which many critics of the efficiency perspective may reject. Finally, from a mainstream perspective, while some redundancy may be needed in the system, the challenge is to ascertain the 'efficient' minimum redundancy needed or consider different ways in which it might be achieved (for example though the use of ex situ gene banks). In other words, resilience for them can be viewed through the lens of efficiency.

These are some of the surface criticisms and counter-criticisms of efficiency and ideas about reductiveness and resilience. But at a deeper level critics of mainstream efficiency object to the fundamental constituent of scientific reductiveness – the idea that things can and should be measured – and indeed that 'if it can't be measured it can't be managed.' From there it seems but a short, and soul-destroying hop to assuming that 'if it can't be measured, it has no value.'

Efforts to assign value (sometimes monetary) to the spiritual or aesthetic fulfilment one may gain from a landscape using an ecosystem services approach, only make things worse by commoditising the uncommodifiable.

So the dis-ease that many have with efficiency is fundamentally a problem with numbers and ratio; a rejection, in the Romantic tradition that has such deep roots in the environmental movement, of the machine-hearted soullessness that it connotes

155 Resilience dictionary, Stockholm Resilience Centre, Available at: http://www.stockholmresilience.org/21/research/what-is-resilience/resilience-dictionary.html

156 Table 1. Ten definitions of resilience with respect to the degree of normativity, Ecology and society, Available at: http://www.ecologyandsociety.org/vol12/iss1/art23/table1.html

157 What is resilience? Stockholm Resilience Centre, Available at: http://www.stockholmresilience.org/21/research/research-news/2-19-2015-what-is-resilience.html

158 Applying resilience thinking, Stockholm Resilience Centre, Available at: http://www.stockholmresilience.org/21/research/research-news/2-19-2015-applying-resilience-thinking.html

Figure 4: Blake's *Newton* measuring the universe. Credit: Wikipedia.

and of the attempt (see Figure 4) to measure the universe.

An efficient system from this perspective is profoundly sterile – it eliminates idleness, lacks superfluity; qualities that poets and writers have always valued as the seedbed of creativity. Resilience, by contrast, with its emphasis on complexity and its acceptance of redundancy is far more appealing; it suggests abundance and a whole that is more than the sum of its parts.

Of course from a mainstream efficiency perspective these emotional, strongly aesthetic responses to the concept may be dismissed as irrational and unscientific. Words and phrases often bandied around such as 'holistic' and 'irreducible complexity' appeal (it can be argued) to people who lack scientific training, who rely too much on false metaphors, and who are fundamentally in search of something to replace the God and the Soul that they can no longer bring themselves to believe in.

What is more, they reject the simplistic idea that scientific knowledge and creativity or 'wonder' are antithetical. They point to many scientists whose efforts to understand the universe through measurement, stem in fact, from a profound emotional and aesthetic appreciation of the natural world and a desire to protect it.

Different emotions, different visions; the debate will run and run as it already has for so long. One's gut feelings may or may not bear scientific scrutiny. Common sense, as famously remarked (if variously attributed), is the sense that tells us that the earth is flat. Nevertheless, the point here is neither to validate nor invalidate the accuracy of these aesthetic responses to 'efficiency' but rather to argue that these responses should be taken seriously and explored respectfully. They are profoundly important in shaping people's arguments about what efficiency is and is not, and what should stand in its place.

5. Conclusions: From efficiency to effectiveness?

To return to the title of this piece: what is efficiency? And is it sustainable? The short answer is: it depends on who you ask.

The word is embedded in discussions about the ills and possibilities of the food system, yet, as we have shown, different people assign very different meanings to it. Some use it as a short hand for sustainability without really thinking about it. Others have their own often inconsistent definition but may disagree with other people's usage. Some argue that the definition of efficiency needs extending to encompass a broader set of indicators. Others still may simply reject its utility as a measure of sustainability *per se*.

Even the process of writing this paper, as we passed drafts among ourselves, adding comments and text, revealed much about our own biases as authors. One of us is perhaps more comfortable with mainstream definitions of efficiency; a second somewhat more 'anti' meat; and the third a romantic despite it all. All these biases will have been shaped by the disciplines we work within, and of course our personal circumstances. We bring our prejudices to our analysis, however impartial we try to be.

In short, the word efficiency has become intellectually, morally and aesthetically overloaded. And since this is so, instead of ignoring these loads, and concluding this paper by proposing our own new and improved definition of efficiency, our real conclusion is that we need to pay attention to the loads themselves. How people think of and use the word efficiency speaks volumes about what people want from and for our food system, about what a 'good' food system is.

And so the longer answer to the question: "What is efficiency? And is it sustainable?" is that in order to understand what it is, and its relationship with sustainability, we need to think about what we really want. Since arguments about efficiency are covertly – and thus confusedly – arguments about goals and ends, then let us make these discussions clearer by bringing them into the open. Let us be explicit that this is what we are talking about and then talk about it. How and why do our wants differ, once we get beyond motherhood and apple pie platitudes, and (how) might we find ways of resolving differences?

To reorient the discourse, we suggest putting the word efficiency aside for a moment, and start thinking instead about effectiveness – about what an 'effective' food system might look like. Effectiveness, unlike efficiency, very clearly betokens that we *want* things from the food system. We may disagree about what these are but at least the emphasis is shifted explicitly onto the outcome, rather than our goals being implicitly and inconsistently tangled up in it, as when discussing efficiency. If we are clear that *outcomes* are ultimately what we are all really talking about, we can have a full discussion about what we want, the routes to attaining them, and where and why we agree or disagree.

Of course an obvious and legitimate response to this suggestion is that we are simply replacing one cloud of confusion with another.

All new terms eventually become dumping grounds for people's values and aspirations – as witness for example, sustainable intensification, agroecology and the inchoate grandmother of them all, sustainability. This is inevitable – it is what happens with language. Effectiveness will soon lose its meaning and need to be replaced.

However, for the short time that they *are* new, these coinages can catalyse fresh thinking. Effectiveness – which we deliberately do not define – simply by shifting the emphasis onto ends rather than means, enables us to talk openly about our values. These are the 'soft' issues that are too rarely discussed openly even though they underpin so many of the disagreements we have.

Effectiveness may also have an unexpected side effect – it may allow us to reinstate the concept of efficiency by circumscribing it, rather than throwing it out with the bathwater. By off-loading from it the weight of people's values, it becomes merely but nevertheless usefully a tool, one of the many that we might use to assess progress towards or against environmental, health, economic and social effectiveness – whatever that is.

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