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Livestock-related greenhouse gas emissions: impacts and options for policy makers

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ABSTRACT

Research shows that livestock account for a significant proportion of greenhouse gas (GHG) emissions and global consumption of livestock products is growing rapidly. This paper reviews the life cycle analysis (LCA) approach to quantifying these emissions and argues that, given the dynamic complexity of our food system, it offers a limited understanding of livestock's GHG impacts. It is argued that LCA's conclusions need rather to be considered within a broader conceptual framework that incorporates three key additional perspectives. The first is an understanding of the indirect second order effects of livestock production on land use change and associated CO_2 emissions. The second compares the opportunity cost of using land and resources to rear animals with their use for other food or non-food purposes. The third perspective is need—the paper considers how far people need livestock products at all. These perspectives are used as lenses through which to explore both the impacts of livestock production and the mitigation approaches that are being proposed. The discussion is then broadened to consider whether it is possible to substantially reduce livestock emissions through technological measures alone, or whether reductions in livestock consumption will additionally be required. The paper argues for policy strategies that explicitly combine GHG mitigation with measures to improve food security and concludes with suggestions for further research.

1. Introduction

The food chain contributes significantly to greenhouse gas (GHG) emissions, both at the national (UK) and international levels. While estimates vary, with ranges given from about 18% (Garnett, 2008; Defra, 2007a) of UK to 31% (European Commission, 2006) of EU total emissions (reflecting, among other things, different methodological approaches), clearly the impact is considerable and commensurate with other energy-intensive sectors such as transport.

It is becoming clear that meat and dairy products are the foods carrying the greatest environmental burden, accounting for approximately half of food-generated GHG emissions (European Commission, 2006; Jan Kramer et al., 1999) and indeed 18% of global GHG emissions (FAO, 2006). However, global consumption of livestock products is growing. Demand for meat and milk is set to double (FAO, 2006) by 2050.

The implications are serious. A global temperature rise of 2 °C above pre-industrial levels, delivers the probability of 'dangerous climate change' (Schellnhuber et al., 2006). To keep below this potentially dangerous tipping point, global GHG emissions need to be reduced by at least 50% and as much as 85% on year 2000 levels (IPCC, 2007). A concurrent challenge is for developing economies to grow so that their citizens' living standards improve. Given current models of development this will lead to an inevitable rise in their per capita emissions; as such, the developed world, which contributes the bulk of present and historical emissions, needs to reduce its GHGs by

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80% or more (Committee on Climate Change, 2008). With the passing of its 2008 Climate Change Act, the UK is now legally committed to doing so.

Meeting this target will require substantial emission cuts by all sectors of the economy and society, including the food system. Clearly food is essential in a way that private cars, for example, are not, and it may not be possible for the food chain to go as far as an 80% reduction. However, in view of the magnitude of its contribution, it is vital that the research and policy community investigates what reductions are possible and how they might be achieved (Garnett, 2008).

Research and policy attention is increasingly focusing on this challenge, drawing largely from the insights gained through life cycle analysis (LCA). Life cycle analysis offers a way of examining a product's environmental impacts at all stages of its production, use and disposal; in the case of food these arise from the inputs to the agricultural process through to consumption in the home and waste disposal. Importantly, the LCA approach not only sheds light on the relative importance of different stages in the supply chain, but also on how changes in one part of the system might affect other parts, or how measures to reduce one environmental impact affect the intensity of other impacts.

Nevertheless while a key advantage of life cycle analysis is the level of very detailed, product-specific information it can provide, it is less able to capture some of the dynamic, systemic challenges posed by our globalised, highly complex food system, as is discussed below. This is an important limitation; perhaps not so much of the tool itself as of the conclusions that policy makers may draw in response to LCA's findings. The UK Government has shown considerable interest in LCA, through its commissioning of studies (Foster et al., 2006; Williams et al., 2006) and its involvement in the development of a standardised GHG footprinting methodology, the PAS 2050 (British Standards Institution, 2008). Retailers and manufacturers in the UK and elsewhere are also adopting this approach, either for in-house analysis of their impacts or, more publicly, by piloting the development of an LCA based 'carbon label' to inform consumers' purchasing decisions (Carbon Trust, http://www.carbon-label.com/individuals/label.html; Project Carbon Footprint, http://www.pcf-projekt.de/main/product-carbon-footprint/). It is therefore essential that the limitations of LCA are recognised.

In particular, some of its findings in relation to livestock production may lead to the adoption of mitigatory measures that are actively counterproductive. It is argued that LCA's conclusions need rather to be examined within a broader conceptual framework that incorporates three key additional perspectives. The first is an understanding of the indirect second order effects of livestock production on land use change and associated CO_2 emissions. The second perspective compares the opportunity cost of using land and resources to rear animals with their use for other food or non-food purposes. The third perspective considers needs—how far humans need livestock products at all.

These perspectives are described in more detail and used as lenses through which to explore both the impacts of livestock production and the mitigation approaches that have been proposed. The discussion is then broadened to consider whether it is possible to substantially reduce livestock emissions through technological measures alone, or whether reductions in livestock production and consumption will additionally be required. Finally, the implications for policy are highlighted and suggestions offered for further research.

This paper draws upon a longer study (Garnett, 2007), undertaken for the Food Climate Research Network (FCRN) project at the University of Surrey, UK. This was based on an extensive review of the literature on livestock GHGs and on related areas of concern, including animal welfare and human nutrition. It also benefited from wide-ranging discussions with stakeholders in the livestock industry, government and non-governmental organisations (NGOs) and from insights gained at a seminar (FCRN, 2007) organised by the FCRN to discuss the study's findings.

2. Livestock and their contribution to GHG emissions: a review

There is a large and growing literature on the GHG emissions associated with livestock rearing (Casey and Holden, 2005, 2006; Cederberg and Mattson, 2000; Cederberg and Stadig, 2003; FAO, 2006; Lovett et al., 2006; Basset-Mens and van der Werf, 2005). The findings broadly conclude that livestock products are GHG intensive compared with other food groups, and that the vast majority of impacts occur at the farm stage, with subsequent processing, retailing and transport playing more minor roles (Berlin, 2002; Foster et al., 2006). Note that caution is needed when comparing the GHG intensity of foods since different products perform different nutritional roles in our diets—these are discussed in relation to the opportunity cost of livestock production, below.

To calculate emissions resulting from UK consumption of livestock products, the basis for calculations is a Government-sponsored study by Cranfield University (Williams et al., 2006)—perhaps the most comprehensive peer-reviewed publication undertaken so far in the UK. The report calculates GHG emissions per kilogram of different livestock products (eggs, milk, beef, pork, sheep meat, poultry). When these per kilogram emissions are multiplied by total consumption of these products in the UK, the rearing of livestock for our national consumption is found to generate 57.5 million tonnes of CO_2e. This figure takes into account imported livestock products and excludes exports. It does not include emissions resulting from slaughtering, processing or other stages. The calculation is approximate but serves as an adequate starting point for analysis.

As a proportion of the UK's total consumption related emissions (a figure that includes the embedded emissions in the goods and services the UK imports but excludes exports—see Druckman et al., 2007; Jackson et al., 2006) then the UK's appetite for meat and dairy products contributes around 7–8% to national GHG emissions, depending on which estimate of total consumption impacts is used. These, the Cranfield analysis finds, are largely attributable to emissions of methane (CH_4) and nitrous oxide (N_2O). Carbon dioxide (CO_2) emissions, arising largely from the use of field machinery, milking parlours and so forth, are less significant for ruminants although for intensive pig and poultry production their importance is greater. Other Northern European studies (the locus of most LCA research) also find that CH_4 and N_2O emissions dominate, with CO_2 playing a less important role (Flessa et al., 2002; Schils et al., 2005; Gibbons et al., 2006; Olesen et al., 2006).

Hence LCA shows that livestock-related emissions are significant, and in the light of global trends in production, are set to grow. Studies also suggest that CO_2 emissions are less of a concern than N_2O and CH_4. However, as will be discussed, the indirect contribution of CO_2 is significant and this has implications for some mitigation options currently being proposed.

3. Beyond livestock LCAs: some broader framing concepts

To gain a broader sense of livestock's impacts, an additional set of framing perspectives is needed, which are referred to as follows: the *second order impacts* of livestock production and consumption; the *opportunity cost* of land and resource use; and the ultimate question of *needs*.

Second order impacts become apparent once one moves away from a 'snapshot' atemporal analysis of GHG impacts towards a more dynamic exploration that takes into account land use change over time. For example, a classic livestock LCA will quantify the GHG impacts associated with the production of a feed crop, taking into account emissions attributable to fertiliser production, machinery, soil N_2O and so forth. This, while a comprehensive and elaborate undertaking, does not take into account the CO_2 releasing impacts of any pasture or forest clearance that is undertaken to make way for feed cultivation.

It would be misleading to suggest that researchers are not aware of LCA's limitations. Indeed many are seeking ways of including land use change into LCA methodology and thinking (Searchinger et al., 2008; Kløverpris et al., 2008; Milà i Canals et al., 2007). To our knowledge, however, to incorporate land use change impacts into livestock LCAs have not yet been attempted.

The *opportunity cost* is essentially a 'what if?' approach, and is a feature, albeit in very limited form, of some consequential LCAs (Dalgaard et al., 2007; Schmidt and Weidema, 2007; Berlin and Uhlin, 2004). It refers to the cost of forsaking the benefits of using land or other resources for one purpose by using them for another. Given global constraints on land, the opportunity cost of using it to rear livestock rather than to grow food for direct consumption needs to be considered.

The third conceptual lens is *need*. Of the goods and services gained from livestock rearing – food, non-food materials and environmental services – this perspective considers to what extent they are supplied in excess of our actual needs. Such an approach contrasts with studies that seek to anticipate and cater for demand (FAO, 2006) and will always be contentious, because definitions of what constitutes 'need' are open to debate (Jackson et al., 2004), and because discussions that implicitly place limits on consumption quite plainly run counter to the way economies work. However, given the extraordinary disparities between the global haves and have-nots, and the absolute limits both on the land available and on the atmosphere's ability to absorb GHGs without major disruption, the needs-based approach demands exploration. Policy makers are currently seeking to negotiate a post-Kyoto framework for global GHG reductions, balancing the environmental imperative against the need for poor countries to develop. NGOs and policy observers have proposed their own frameworks, of which perhaps the most famous is the Contraction and Convergence proposal (Global Commons Institute, http://www.gci.org.uk/contconv/cc.html), although there are also variants (Baer et al., 2007). These approaches are essentially needs-based in that they implicitly or explicitly set limits on human demands.

These three perspectives frame our analysis of the livestock–GHG relationship and give rise to the following specific questions:

- *Second order impacts*: Are the full benefits and disbenefits of livestock products, including non-food goods, accurately accounted for in LCA?
- *Opportunity cost*: We have to eat—would plant based substitutes be more GHG efficient?
- *Needs*: Is it possible to define how much livestock production human society 'needs' and does production fall short of, or exceed this level?

The first two questions relating to the second order impacts and opportunity costs are, as will become clear, interlinked and cannot be discussed separately. They are considered in relation to the inputs required for livestock production. The needs question is discussed in the context of three key outputs from livestock production, food (nutrition), leather and manure.

3.1. *The inputs to the production system: the second order impacts and opportunity cost*

The main input to livestock rearing is land. This can be subdivided into: land for cereals, for oilseeds (and other proteins), and for pasture. Byproducts from other food and agricultural sectors constitute an additional input. Energy (fossil fuel-derived for industrialised systems) is also needed but is not discussed here since impacts relative to other emission sources are low. Through the use of renewables such as wind and waste-derived biogas they may also be more straightforward to tackle.

3.1.1. *Land for proteins: Soy and the second order impacts of land use change*

Oilmeals are a key element of the livestock diet. Soymeal is particularly valued as a high quality protein, carrying the highest value of the oilseed cakes (USDA, 2008a). While the oil has its uses in industrial food manufacture the cake is the more valuable fraction, accounting for around two thirds of the crop's economic value (FAO, 2008). In some years demand for the cake actually drives oilseed cultivation.

As an input to the livestock production system, LCAs do of course include in their analysis the emissions arising from the production of soy, including its associated inputs (see for example Williams et al., 2006). Crucially, however, they do not take into account a potentially significant indirect impact; land use change arising from soy production and the associated release of CO_2.

Soy cultivation is a major driver of deforestation in the Brazilian Amazonian region (Nepstad et al., 2006; WWF, 2004). In the decade up to 2004, industrial soybean farming doubled its area to 22,000 km^2 and is now the largest arable land user in Brazil (Elferink et al., 2007). Moreover, soybean cultivation not only makes use of land in its own right, but is also an important 'push' factor for deforestation by other industries; it takes land away from other uses, such as smallholder cultivation and cattle rearing, and pushes these enterprises into the rainforest (Fearnside, 2007; Nepstad et al., 2006). Additionally, it provides income to purchase land for other purposes, including logging.

It has been estimated that the annual net emissions from Brazilian Amazonian deforestation, based on the average deforestation rate of 19,400 km^2 per year for the 2007 period, was approximately 191 million tonnes of CO^2-equivalent carbon, or 700 million tonnes CO_2e (McAlpine et al., 2009). This represents more than 2% of global GHG emissions. The main cause is cattle ranching and in this case the link between land use change derived CO_2 release and livestock production is very direct. The EU is a major beef customer (USDA, 2008b).

Soy is also an important, if unquantified contributor and its influence is growing (McAlpine et al., 2009). Further expansion of soy and cattle ranching combined could occupy an additional 1.4–1.7 million km^2 in Brazil alone, equal to the entire cultivated cropland area of the United States; around a quarter of this land is located in the Amazon (Nepstad et al., 2006).

The EU represents a major export market, accounting for 32% of Brazil's soy animal feed exports in 2006/2007; producing this volume has been calculated to require 50,000 km^2 of Brazilian land. For the UK specifically, the Brazilian land take amounts to over 6700 km^2 (Friends of the Earth Netherlands, 2008).

The author is not aware of research that seeks to quantify what proportion of soy-related land use has contributed to deforestation and hence what CO_2 is attributable to soy. However, as a more general estimate, the Food and Agriculture Organisation (FAO, 2006), calculates that globally, livestock induced land use change generates 2.4 billion tonnes of CO_2 a year, equivalent to approximately 7% of global GHG emissions. These emissions arise not only from soy production but also from the cultivation of other feed crops, and from the encroachment of grazing into forested areas.

In summary, the production of agricultural products overseas for UK consumption, including but not limited to soy, can cause changes in land use, which in turn gives rise to releases of stored carbon. These emissions are not usually captured in LCAs of livestock production; further research is needed to assess how significantly they add to current estimates of the UK's livestock GHG emissions.

3.1.2. *Land for cereals and the opportunity cost: grains for people or grains for livestock?*

Cereals are a major source of nutrition for pigs, poultry, dairy cows and for cattle in intensive beef systems. More than half of the UK's cereal output is used to feed farm animals (Defra, 2006). Globally livestock have been estimated to consume a third (FAO, 2002) or more (37%) of world cereal output (WRI, 2004). While livestock in the developing world generally consume far fewer cereals and rely more on foraging and byproducts, this situation may change (Keyzer et al., 2005), as production systems intensify and as we see a growth in chicken and pig production where grains feature heavily in their diets.

This cereal dependency has led commentators to note that it would be much more efficient for humans to consume cereals directly since much of the energy value is lost during conversion from plant to animal matter (Goodland, 1997; Gold, 2004; Gerbens-Leenes and Nonhebel, 2002). Efficiency is defined here as fewer GHG emissions per unit of nutrition although efficiency can also refer to, for example, water use.

Various authors have calculated how much plant food is required to produce an equivalent quantity of animal food. This 'feed conversion efficiency' has a major bearing on GHGs since losses of nutritional energy through the production chain – from plant to animal nutrients – means that more GHGs are emitted for a given quantity of nutritional output. Table 1 shows reported efficiencies for industrialised systems.

Note that the efficiency of beef cattle is hard to estimate since much will depend upon the breed and the feeding regime; the feed conversion ratio can vary between 5 and 10. The issues are different too, since grassfed cattle will do not consume any grain. In the developing world, feed conversion ratios will be much lower due to differences, among other things, in animal breeds and in the digestibility of the feeds consumed.

Described in terms of its energetic value (calories available for consumption) too, the conversion efficiency of animal based foods is significantly lower than that of plant foods, as Wirsenius (2003) shows. Nevertheless, it is of course the case that if people did not consume livestock products, fewer cereals would be required for livestock but more for direct

Table 1 – Feed conversion efficiency for farm animals.

	Feed conversion (kg cereals: kg animal weight)—finishing stage only	Feed conversion (kg cereals: kg animal weight)—overall	Comments	Sources
Broiler chickens	1.8	1.7	UK data	Biffaward, 2006; British Poultry Council 2008, personal communication
Laying hens		2	North American data	Chen et al., 2005
Pigs	2.75	2.43	UK data	British Pig Executive, 2007; British Pig Executive, 2008
Cattle		5–10		Meat and Livestock Commission, 2007

human consumption. It is possible then that a reduction in livestock consumption might lead to an increase in the land area required to grow cereals, perhaps leading to additional land use change derived CO_2 emissions.

Srinivasan et al. (2006) consider the issue of cereal requirements, albeit from a different angle—nutritional recommendations. The authors examine, for OECD countries, what would happen to the production, consumption, and trade of key commodities (including cereals, sugars and livestock products) if populations in OECD countries were to eat in accordance with WHO/FAO nutritional guidelines. The study finds that to stay within recommended limits on fat intakes, reduced consumption (and hence production) of livestock products is required while a corresponding increase in the production of substitute foods (cereals) will also be needed. However, it finds that the increased need to grow cereals for direct human consumption only very slightly outweighs the corresponding decline in feed cereal requirements; in effect, the amount of cereals grown stays virtually the same.

Viewed in terms of overall GHG emissions too, research suggests that life cycle GHG emissions arising from plant based foods tend to be lower. For example, 1 kg of UK reared beef is associated with approximately 16 kg of CO_2e as compared with 0.8 kg of CO_2e per kg of wheat (Williams et al., 2006) and 0.4 kg of CO_2e per kg of in-season lettuce, although for the few fruits and vegetables that are imported by air, the impacts are comparable to meat products (Edwards-Jones et al., 2008b).

However, these foods perform very different nutritional roles in our diets and may be eaten in very different quantities. A comparison of calories *in* versus calories *out* is too simplistic, as is an assessment of GHG emissions per kg of product consumed; it is important to consider whether plant based foods are able, nutritionally speaking, to substitute for animal products. These issues are explored in the discussion on needs, below.

Distinguishing between livestock types, LCAs find that since poultry and pigs are much more efficient converters of plant energy into animal energy and produce far fewer CH_4 emissions, their GHG burden is lower. It has been suggested that one approach to reducing livestock emissions may be to consume these in preference to ruminant meat (Committee on Climate Change, 2008) and to limit ruminant meat consumption (McMichael et al., 2007). The trends show that worldwide, we are in any case consuming more pig and poultry products (FAO, 2006).

Nevertheless it is also the case that the monogastric diet is cereal and oilseed dependent to a much greater extent than that of ruminants. More so than ruminants, pigs and poultry consume grains that humans could eat directly and so the opportunity cost of cereal use is particularly relevant in their case. They are also more heavily implicated in soy production than ruminants and hence with CO_2 emissions arising from land use change—pigs and poultry account for around 60% of soymeal consumption in the EU (Friends of the Earth Netherlands, 2008). The substitution of white meat for red is therefore questionable. This said, for current industrialised systems of production and expectations of productivity, cereal feeding is essential to the diets of all livestock types. A diet of grass and byproducts alone would support considerably fewer cattle.

Note that feed conversion efficiency accounts only for the edible outputs of the livestock sector. The calculation does not take into account the non-edible outputs such as manure, leather, wool and so forth, which are discussed later. If these are considered, the relative efficiencies between livestock types might look different (cattle produce leather, manure and traction power whereas chickens do not) and the differences between plant and animal foods might also narrow—although plants also provide non-edible goods, such as thatching material.

This is also the case when considering the GHG impacts arising from livestock production. The LCAs reviewed here and elsewhere (Garnett, 2007) attribute all emissions to the edible outputs of production. Properly speaking, however, these should be divided among the various outputs, such as leather or wool. One LCA of leather production (Milà i Canals et al., 2002) includes a proportion of the livestock rearing emissions in its quantification, assuming, based on economic allocation, that 7.7% of all agricultural impacts are attributable to the leather itself. This, if the logic were carried to its natural conclusion, would reduce emissions from the edible output by 7.7%. If allocations were made to all the other non-food outputs of livestock production, the GHG emissions attributable to meat and dairy products will be lower still.

This again, illustrates how the second order impacts of livestock production (avoided need to produce alternatives) may alter the conclusions of classic LCA, this time by reducing per-output impacts slightly, although overall livestock emissions will stay the same. Once again, most LCA studies tend not to take these benefits into account in their calculations.

3.1.3. *Pasture land: second order benefit or opportunity cost?*

In addition to arable land for feed, ruminants also make use of poorer quality grazing land. Livestock rearing can thus been seen as resource efficient—if we did not rear them we would have to find and plough alternative land. This would require not only the use of inputs such as fertilisers, but could also lead to CO_2 releases when undisturbed land is ploughed for arable use. Thus, livestock can help avoid the emission of GHGS—a second order benefit. Indeed in many land areas of the UK (and elsewhere) no other form of food production is possible.

Moreover, an important function of upland livestock production in the UK is that it gives economic value to grasslands; these act as sinks for carbon. Any changes in land use that disrupt the soil (ploughing, say, or construction) will cause releases of stored carbon into the atmosphere. Hence livestock have an important role to play in maintaining pasture land and, as such, in preventing it from being used for another, carbon releasing purpose. They can even add to the carbon stock of the soil: research finds (Allard et al., 2007) that on temperate unfertilised grasslands where cattle are reared without the use of feed inputs or additional fertiliser, the carbon sequestering role of livestock outweighs their CH_4 and N_2O emissions.

However, grasslands are not always a ‘free’ resource. In all, some 66% of the grassland area in the UK receives nitrogen fertiliser applications (Defra, 2007b). Lowland pastures can be heavily fertilised, leading to N_2O and CO_2 emissions. While some sheep and cattle are indeed left for much of their lives to graze on the uplands, they are usually finished on fertilised lowland grass, perhaps supplemented with concentrates—without this extra input, the meat to bone ratio would be too low to be economically viable. In the winter, dairy and beef cattle also eat grass in its fermented form as silage, a process which requires energy to produce. If livestock were only reared on land unsuited to other forms of food production, without the use of additional food inputs, the numbers that could be supported would be far fewer; this scenario is discussed below.

Moreover when land is overgrazed the combination of vegetative loss and soil trampling can lead to soil carbon losses and the release of CO_2 (Abril and Bucher, 2001; Abril et al., 2005). Overgrazing is a significant concern in the developing world and it has been estimated that 20% of land globally is degraded—up to 73% in drylands (FAO, 2006). The problem exists in the UK too, although to a lesser degree, and undergrazing can also cause problems (English Nature, 2005). The UK is also implicated in overgrazing-related carbon losses overseas when our demand for major agricultural commodities (often grown to feed livestock), pushes livestock farming onto increasingly marginal and vulnerable pasture lands where soils are quickly degraded (FAO, 2006).

Additionally, while livestock are indeed reared on terrains unsuited to other forms of *food* production, there may be scope to investigate the diversion of some pasture land (on a case by case basis) to forestry or other biomass production—activities which not only also sequester carbon (as with livestock) but also substitute for fossil fuels. The opportunity cost of using this land for livestock rearing needs, therefore, to be compared with these other possibilities.

3.1.4. *Byproducts: second order benefit or opportunity cost?*

In addition to cereals and oilseeds, animals are fed a wide range of byproducts from other agricultural sectors such as molasses cake, brewers grains, vegetable residues and rice husks. Their consumption of these genuine 'leftovers', is resource efficient; we, by consuming meat and milk are indirectly consuming 'waste' and so the need to grow alternative foods is avoided. This, as in the case of low quality grazing land, can be seen as a second order benefit, leading to avoided GHG emissions.

However to understand how significant this benefit might be, it is necessary to consider what level of livestock production such byproducts actually support. Fadel (1999) quantifies the volume of byproducts (including soymeal, which is hardly a byproduct) available globally in 1993 and concludes that their nutritional content is theoretically sufficient to provide for the production of 80% of that year's total global milk output. The analysis does not, however consider the location of the byproducts in relation to the livestock and the possibility that the environmental impacts of transporting them might actually outweigh the resource efficiency gains. Moreover he considers only dairy cows and not beef cattle, pigs and poultry. Clearly there are not nearly enough byproducts available to feed all the animals that we want to eat.

There may also be an opportunity cost in using byproducts to feed livestock. There is currently enormous interest in food-waste as a feed stock for biogas production, and a number of anaerobic digestion plants are either being developed or are running in the UK. The value of using byproducts to feed animals as compared with using them to generate energy needs careful examination; the 'right answer' is likely to vary depending on context.

The cultivation of crops for biofuels production is an emerging, if contentious issue, and relevant to livestock production since the refining of oil or starch grains to produce biodiesel or ethanol gives rise to protein-rich byproducts, which can be used to feed animals (Cottrill et al., 2007). It has been suggested that fewer dedicated feed crops, particularly soy, potentially need to be grown-a CO_2 benefit in terms of avoided land use change (Renewable Fuels Agency, 2008). However, the value of animal feed here is that it improves the GHG balance of first generation biofuels rather than the other way round. It should also be noted that sugarcane, arguably the biofuel feedstock with the most potential for GHG savings (compared with petroleum) does not yield byproducts suitable for animal feed (Renewable Fuels Agency, 2008).

Perhaps more importantly, the benefits should be considered in the broader context of global food supply. As demand for biofuels grows, the price of grains (in a land constrained world) will rise (OECD-FAO, 2007). Cereal price rises will affect and push up the cost of intensive livestock production; but on the other hand the cost of protein inputs may not be affected since the co-products of biofuel production will be widely available (Cottrill et al., 2007; Renewable Fuels Agency, 2008). It may be that the overall long term effects on livestock costs are neutral. In the case of food for human consumption, however, the competition between biofuels and food production remains since there are no co-products from biofuel suitable for direct human consumption. Hence over time biofuels production might actually favour the production of animal products relative to food crops and in so doing indirectly contribute to all the direct impacts (CH_4 and N_2O) associated with livestock production. This is a speculative argument only, but one that merits further investigation.

3.2. *Livestock outputs: needs and substitution costs*

Animals provide us not only with food, but with non-food goods such as leather, manure, and wool; and with benefits such as soil quality, species diversity and landscape aesthetics. The questions that arise in relation to these outputs are: to what extent does society need these goods? To what extent are substitutes available at a lower GHG cost? These questions are discussed in relation to three key outputs—food, leather and manure.

3.2.1. *Food*

Clearly food is the major and most important output from livestock farming. Meat, eggs and dairy products provide a range of essential nutrients, including protein, iron, calcium, vitamin B12 and fat, and if we did not consume animal foods we would have to obtain these nutrients from somewhere else.

The questions to consider therefore are whether people actually need animal source foods to obtain key nutrients; and if not, whether their substitution with plant foods would produce more or fewer GHG emissions.

Regarding need, WHO advice does not specify desirable levels of meat and dairy intakes (as it does for fruit and vegetables) but rather sets out recommendations for fat, protein, iron, calcium and so forth. These can be supplied by a variety of foods and indeed a considerable body of research shows that a varied diet of plant foods is perfectly able to provide us with the full range of nutrients needed to maintain a healthy diet (American Dietetic Association, 2003; Appleby et al., 1999; Key et al., 1999; Sanders, 1999; Millward, 1999).

The second question – the environmental cost of substitutes – then arises. It was noted that the GHG burden of plant based foods tends to be lower but also emphasised that comparisons on a CO_2e/kg of food consumed basis are not meaningful. A kg of broccoli is not comparable to a kg of sugar or beef. Nevertheless, some studies have sought to compare the GHG emissions of vegetarian and meat-based whole meals, both balanced nutritionally. Carlsson-Kanyama (1998) shows that a pulse-based vegetarian meal offers the same nutrition as one based on pork at considerably less GHG expense. A later study (Davis and Sonesson, 2008) confirms this finding.

This said, while plant foods can provide adequate nutrition at lower GHG 'cost,' much depends on the overall diet. Among poor societies where meals are overwhelmingly grain or tuber based, where access to a nutritionally varied selection of foods is limited, and where there are serious problems of mal- and under-nutrition, keeping a goat, a pig or a few chickens can make a critical difference to the adequacy of the diet (Neumann et al., 2002).

On the other hand, in rich societies suffering from the burdens of over-nutrition, such as cardiovascular disease and diabetes, a diet high in fat-rich animal products, can be actively deleterious. In this case, a reduction in meat and dairy consumption may confer health benefits (Srinivasan et al., 2006; McMichael et al., 2007).

In short, our 'need' for livestock products very much depends on who we are, on our ability to access a variety of substitute foods and on what policies are put in place to ensure food security. These factors are critical when considering how far we might need to reduce our consumption and production of livestock products, as discussed below.

3.2.2. *Leather*

Leather, is another key output of livestock production. As for food, its use raises the question both of the opportunity cost (what is the GHG of producing a substitute?) and more fundamentally that of need—do we need leather in the quantities available to us?

The GHG cost of substitute materials is in fact an under researched area. While there are some LCAs of alternative materials (Kalliala and Nousiainen, 1999; Laursen et al., 1997), the author is not aware of comparative studies. There is a need for more research in this area.

The amount of substitute materials required will clearly depend on how far we judge there to be a need for a durable flexible material such a leather, and which leather products are essential. Such judgements will always be arbitrary. Traditionally footwear has been the main output of leather production: the FAO (2003) gives footwear and nothing else as an indicator of trends in the production and trade of manufactured leather goods. Using this as a very crude marker of need it appears that the proportion of light bovine leather going into shoe uppers, still the chief end use, has levelled off at around 56%. If sheep and goat leathers are also taken into account, less than half the world's total leather output is used for footwear. This is a somewhat speculative argument, but it serves to indicate that the 'need' for leather is almost certainly less than the actual supply, although by exactly how much is not known. If livestock production were to fall, people would not go barefoot. Measures to reduce livestock numbers in order to cut GHG emissions would not necessarily require the production of more leather substitutes; some of the leather goods available are not really needed and so demand is highly elastic.

3.2.3. *Manure*

Livestock manure is a mixed blessing. On the one hand, it contributes vital nutrients to the soil; it has been estimated that globally, around 22% of total nitrogen and 38% of phosphate applied is of animal origin, over half of which comes from beef cattle (United Nations Environment Programme, undated). Manure can improve the quality and fertility of soil and it has been shown that soil fertilised with manure is more biologically active and fertile than soil fertilised by mineral fertilisers alone (Fließbach et al., 2007). Manure can also build the carbon storage potential of the soil and so help remove carbon from the atmosphere (FAO, 2001).

As a natural source of nitrogen and other mineral inputs, manure also helps avoid the need to produce, transport and use energy-intensive synthetic fertilisers. This said, substitute materials, such as compost can also have these properties (Bhogal et al., 2007). Incorporating grass/legume leys into a crop rotation can also increase soil organic carbon (Schjønning et al., 2007). While in practice livestock fit well into such rotational systems, there may be scope for using grasses in stockless systems as a feedstock for bioenergy production, a possibility that is currently being investigated (European Environment Agency, 2007).

As with artificial fertilisers, however, manure emits N_2O and CH_4 as it breaks down in the soil. Manure-derived emissions contribute to more than 5% of total anthropogenic GHG emissions, with N_2O the main culprit (FAO, 2006) and manure is particularly problematic when overly abundant, as can be the case in intensive livestock systems. Moreover, as already observed, a third of all cereals grown worldwide are used to feed animals, so in effect, some of their manure is used to sustain their own existence.

In conclusion, livestock do indeed yield valuable outputs. A certain level of livestock production can actively help tackle climate change, by contributing to soil carbon sequestration and by making use of otherwise unproductive land, so avoiding the need to plough alternative land. The ability of livestock to consume crop residues and byproducts that are inedible to humans is resource efficient and leads to GHG avoidance, provided the advantages of substitute uses (such as biogas production) do not outweigh their benefits as an animal feed. Manure can improve soil quality.

Nevertheless at *current* levels of production and consumption – and even more so at projected future levels – the disbenefits of livestock with respect to GHG emissions far outweigh the benefits. Clearly ways of tackling the GHGs generated by livestock are urgently needed.

4. Mitigation options

Can GHG emissions from livestock be reduced? Might there be different ways of feeding, breeding, or managing animals that would keep N_2O and CH_4 emissions down?

A growing international academic and policy literature is devoted to these questions (Hensen et al., 2006; O'Hara et al., 2003; Weiske, 2005). Broadly speaking, from our review of the literature, four main approaches to mitigation emerge. These focus on: (1) improving productivity; (2) changing the management system; (3) managing the outputs; and (4) reducing livestock numbers. The full range is considered elsewhere (Garnett, 2007); here, the discussion is limited to two strategies which most clearly require re-examination in the context of the three perspectives – second order impacts, opportunity costs, and need – defined above. The first focuses on modifying livestock diets to improve productivity; the second on reducing the overall numbers reared. As such they represent two contrasting perspectives on tackling livestock emissions; one technology-oriented, and the other emphasising behaviour change. It is, moreover, necessary to consider whether either alone will suffice.

4.1. *Improved productivity*

Many studies conclude that diets rich in concentrates (cereals and oilseeds) are not only more digestible for dairy cows but also increase their milk output. This means that CH_4 per unit of output will decline (Weiske, 2005; Garnsworthy, 2004). The same applies to beef cattle. Although there will be additional GHG emissions associated with the production of feed inputs, these, it is found, do not outweigh the benefits of reduced methane output (Williams et al., 2006; Cederberg and Mattson, 2000).

Crucially, however, these studies do not take into account the potential second order impacts of dietary change. A diet richer in cereals and oilseeds may reduce CH_4 emissions but can give further impetus to the clearance of land elsewhere to grow these feedstuffs. Moreover, the use of the meal fraction of oilseeds as an animal feed improves the viability of growing oilseeds in general (including for biofuels), prompting further land clearance for production. A greater diversion of cereals to feed animals may mean that more marginal land is cleared by nutritionally vulnerable populations to grow food for direct consumption or for grazing their livestock which have been shunted off more economically viable pastures. Breeding strategies are geared towards producing livestock that perform well (in terms of productivity) when fed concentrates-rich diets, with less priority placed on other traits such as their suitability for survival in less hospitable upland or marginal areas. The livestock herd thus becomes dependent on these inputs. Paradoxically while the FAO (FAO, 2006) quantifies livestock induced land use change (as highlighted above) it nevertheless advocates this dietary 'improvement' approach (within overall recommendations for improved efficiency), so failing to consider the logical consequences of its own analysis. In short, mitigation approaches that advocate feeding greater levels of concentrates may be damaging when viewed from a broader perspective.

The feed-breed approach is of course only one of the measures being proposed. Others such as nitrogen optimisation and manure management, are not discussed here but are likely to help reduce emissions. Mitigation models for UK agriculture as a whole indicate that GHG reductions of 25–30% by 2020 are possible (Committee on Climate Change, 2008) while the UK milk industry has set itself an aspirational goal of reducing milk-related GHGs by 20–30% by 2020 (Defra, 2008); both, however, factor in the deployment of feeding strategies that, as has been argued, may be counterproductive.

4.2. *Fewer numbers*

More broadly this anticipated level of reduction begs the question: are such measures sufficient? Demand for meat and dairy products is set to double by 2050, a combination of population growth and an increase in per capita consumption of these products. Even if ambitious – and as yet unproven – emission reductions of 50% were possible, these gains would be cancelled out by the growth in livestock numbers. Hence, while important, technology and better management alone are highly unlikely to deliver absolute reductions in GHG emissions. It is also necessary to consider – as others have argued (Goodland, 1997; Gerbens-Leenes and Nonhebel, 2002; Gold, 2004) – reducing our consumption of livestock products. The following paragraphs examine what cuts might be needed, and by whom.

4.2.1. *Reducing consumption in the developed world*

On average, in 2050, each person on the planet will be consuming 52 kg of meat and 115 kg of milk a year, considerably more than consumption levels today (Table 2).

However these global consumption averages disguise huge global inequalities. Figs. 1 and 2 show the anticipated consumption trajectories for rich and poor country populations.

The trend lines do not cross, and even by 2050, people in the developing world are anticipated to consume only half as much meat and a third of the milk that developed world populations consume today.

Thus, when considering the level of reductions needed, one place to start is with the livestock-dominated diets of people in developed countries, and to consider what the effect on global volumes would be if rich world peoples reduced their consumption to levels that populations in the developing

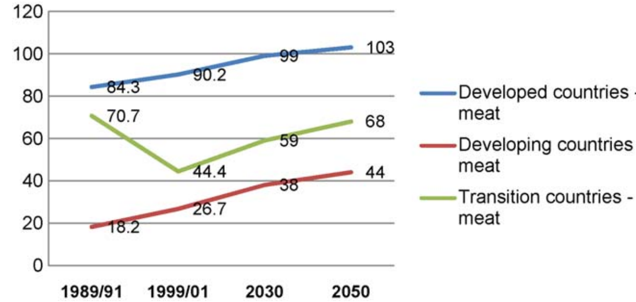

Fig. 1 – Projected trends in per capita consumption of meat products to 2050 kg/person/yr. ***Source*****: World Agriculture: Towards 2030/2050.**

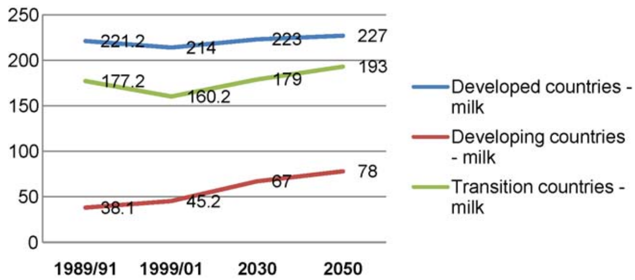

Fig. 2 – Projected trends in per capita consumption of milk products to 2050 kg/person/yr. ***Source*****: World Agriculture: Towards 2030/2050.**

world are anticipated, in 2050, to consume. This would be in keeping with the principle of global equity, since it entails a reduction by rich people (who are not, generally, nutrient deprived) but also allows for higher consumption for nutritionally vulnerable developing world populations.

Figs. 1 and 2 show that by 2050, developing world peoples are projected to consume 44 kg of meat and 78 kg of milk annually. While this represents a considerable increase on their meat and milk consumption levels today, developed world populations would need to halve their meat consumption and reduce milk intakes by nearly two thirds.

Table 3 illustrates what happens when the anticipated reduction in per capita consumption is multiplied by the anticipated population in developed and transition countries for 2050, and this figure then subtracted from the overall anticipated demand for meat and dairy products. It finds that developed world cuts alone achieve a 15% overall reduction in 2050 anticipated world meat volumes and 22% cut in milk.

However, these reductions are insufficient since, due to growth in consumption in the developing world, these lower figures *still* represents an increase on global 2000 consumption levels of around 70% for meat and 45% for milk. This translates into a very great increase in global livestock GHGs at a time when subtantial global cuts will need to have been achieved.

4.2.2. *Meat and dairy consumption: a global no-growth scenario*

A second approach then is to consider a no-growth scenario; what would average per capita availability be if meat and dairy production were kept at year 2000 levels? On current population projections it appears that per capita consumption of meat and dairy products would be as low as 25 kg and 53 kg a year respectively—or 500 g meat and 1000 ml milk a week. This is approximately the average level consumed by people in the developing world today. Others (McMichael et al., 2007) adopting a slightly different approach for meat only (and using a 2005 consumption baseline) find annual per capita intakes to be a slightly higher 32 kg.

Note that even with zero growth in production and consumption, there will be no actual decline in livestock emissions; to achieve reductions, considerable technological/managerial innovation will additionally be required.

4.2.3. *Ecological 'leftovers' approach*

A third approach is to take ecological capacity as the ultimate constraint and to quantify what level of livestock production and consumption would be possible. This would need to assess what land and byproducts are available for livestock that are genuinely unsuited to other purposes, bearing in mind both the second order impacts of land use and the opportunity cost of using these resources for livestock rather than for

Table 2 – Meat and dairy demand in 2000 and 2050.

	2000 (Population 6 bn)	2050 (Population 9 bn)
Average *per capita* global demand—meat (tonnes)	0.038	0.052
Average *per capita* global demand—milk (tonnes)	0.097	0.115
Total demand—meat (tonnes)	229	465
Total demand—milk (tonnes)	580	1043

Source: FAO, 2006.

Table 3 – Effect on livestock production of developed world cuts in consumption.

	Population 2050 (bn)	Projected T/person/yr 2050	Total anticipated consumption Mill T 2050	Total consumption all at 2050 developing world levels mill T	% Reduction in consumption compared with B.A.U projections
Meat					
Developed countries	1.019	0.103	105	44.8	
Developing countries	7.51	0.044	330.4	330.4	
Transition countries	0.343	0.068	23324000	151	
World meat	8.92	0.215	458.7	390	15
Milk					
Developed countries	1.019	0.227	231.3	794.8	
Developing countries-	7.51	0.078	585.7	585.7	
Transition countries	0.343	0.193	66.2	267.5	
World milk	8.92	0.498	883.2	692	22

Source: Based on data presented in FAO, 2006.

something else, such as energy production. It would then be necessary to calculate how many livestock numbers could be supported, without the need for external inputs, and at sustainable stocking levels that do not lead to overgrazing. The number of livestock we could rear and ultimately consume would be bound by these absolute limits.

Note that the 'ecological leftovers' approach leads to genuine GHG benefits, since it maximises livestock's carbon sequestering and resource efficiency functions (thus reducing the need for substitute crop production elsewhere) while minimising the negative impacts arising from intensive livestock. The trade off will be higher methane emissions per unit of milk or meat produced, but these are outweighed by the significant absolute reduction in numbers.

Once again, technological research and development is vital – particularly into the breeding of animals suited to marginal areas – but it is likely that even so, the absolute sustainable level of consumption will be lower than any of the figures given above. This is a radical scenario—but in the absence of additional planets to support the lifestyles we want, it may be the only viable option.

5. Discussion

By 2050 the global population is projected to top 9 billion. Demand for land, food and energy will grow. If land is used for livestock, there will be less available to grow other food or biomass. In parts of the world with access to fertilisers and other inputs, the response will be to intensify production, leading to a range of environmental problems including soil and water pollution (IAASTD, 2008). Elsewhere, where resources are lacking, the consequences will be soil degradation and dwindling yields (FAO, 2006).

Livestock contribute significantly to global GHG emissions and, at a time when the world urgently needs to achieve deep emission cuts from all quarters, consumption and production is set to grow. While life cycle analysis highlights the GHG intensity of livestock products it fails to capture the full disbenefits arising from livestock-related land use change, can give a distorted impression of the sustainability of pigs and poultry relative to ruminants, and can prompt mitigation strategies that are counterproductive. Policy needs to be aware of LCA's limitations. It also needs to go beyond approaches that anticipate demand and start considering what people actually *need* to ensure equitable sustainable development. As such, policy makers will need to make decisions about the environmental opportunity cost of using land and resources for livestock rather than for other purposes.

While technological and managerial innovations are vital, the global community is unlikely, with these alone, to achieve the deep emission cuts that are needed. Substantial reductions in meat and dairy consumption are needed. What level of reductions might be required is not yet clear.

The paragraphs above indicate the per capita global intakes for 2050 that will lead to no-growth in emissions; this combined with technological improvements will go some way to reducing livestock emissions absolutely. Society may, however, need to go further. To achieve radical cuts, an 'ecological leftovers' approach may be required. This will entail rearing animals on land areas and on byproduct resources that are unsuited to other purposes. This approach can lead to genuine environmental benefits; with livestock actively helping to store carbon and to maximise use of marginal land and resources. However production at these levels is likely to lead to very considerable (and as yet unknown) reductions in the amount available for consumption.

All this has major policy implications, both for the UK and the global policy community. Given the twin global challenges of ensuring food security and reducing GHG emissions, the main policy imperative is for decision makers at every level – local, national, regional and international – to explicitly marry these two goals. The priority should be to develop systems of food provisioning that supply populations with maximum nutrition at minimum greenhouse gas 'cost.'

This is an ambitious goal and diverse policy areas will be affected, including agriculture and rural development; trade; employment; urban planning; health, public procurement and sustainable consumption and production. The full panoply of policy tools will need to be deployed—fiscal, regulatory, and voluntary. In view of the 2009 Copenhagen climate change summit, where a global deal on GHG reduction is being sought, now is the right time to take action.

A great deal of research is clearly needed, so that policy can move in the right direction. A number of research questions have been raised above and this paper concludes by drawing them out as recommendations for further policy-oriented research. The questions are specifically grounded in the UK context but they are clearly relevant to all countries.

- *Land use*: Quantify CO_2 emissions arising from land use change attributable to livestock consumption in the UK and examine how this affects the GHG 'hierarchy' of different livestock products. Broader research looking at all the land use change impacts of all food groups is also needed.
- *Ecological leftovers*: Define what land areas of the UK can be classed as suitable only for grazing and quantify the volume of byproducts available for livestock consumption that does not compete with other uses. Assess how many and what kind of livestock could be supported and quantify the subsequent volume of meat and dairy products available for national consumption.
- *Breeding*: Examine what breeding and other strategies are needed to increase the resilience and productivity of grazing livestock reared on upland and marginal areas; adopt comparable breeding strategies for monogastrics.
- *Biofuels and biomass*: Examine the potential long term relationship between biofuels and animal production; assess whether first generation biofuels help or hinder certain types of livestock production and what the effects on GHG emissions might be. Consider what scope there might be for biomass production in upland areas.
- *Nutritional recommendations*: Assess the GHG implications of the UK's current dietary recommendations (the Eatwell plate—Food Standards Agency, http://www.eatwell.gov.uk/healthydiet/eatwellplate/); examine how alternative 'plates' would meet nutritional requirements at lower GHG cost.
- *International development*: Consider, for the developing world, the role and utility of livestock rearing for vulnerable

peoples practicing subsistence agriculture; and in assess the contribution livestock make to household economic and food security. Examine how international development strategies could be reoriented to maximise food security at minimum GHG cost while safeguarding the benefits that vulnerable peoples derive from livestock keeping.

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