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Grazed and confused?

Ruminating on cattle, grazing systems, methane, nitrous oxide, the soil carbon sequestration question – and what it all means for greenhouse gas emissions

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Preface

This report is the collaborative effort of individuals at the Universities of Oxford, Aberdeen and Cambridge in the UK; Wageningen University in the Netherlands; the Centre for Organic Food and Farming (EPOK) at the Swedish University of Agricultural Sciences (SLU); the Research Institute of Organic Agriculture (FiBL) in Switzerland; and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia. All the participating organisations contributed intellectual and financial support to the project. The project was led by the Food Climate Research Network at the University of Oxford.

The work is motivated by our desire to provide clarity to the often highly polarised debate around livestock production and consumption, and the merits or otherwise of different production systems. At its most extreme, we see an opposition between those who view grazing ruminants as cause of (most of) our planetary woes, and those who believe the exact opposite, arguing that 'grassfed' cattle offer a route to environmental – including climatic – salvation. Of course most people do not hold these extreme views but many, including those with influence, are also somewhat confused. Should we eat meat and other animal products? Or should we not? If we do, is beef bad and chicken better? Or is it the other way round? Is grassfed good for the planet or bad?

Ultimately in the context of planetary boundaries on the one hand and the need for human development (in its widest sense), the 'big question' that needs answering is whether farmed animals fit in a sustainable food system and if so, which systems and species are to be preferred. This report does not address this enormous and difficult question, particularly if sustainability is defined in its proper and widest sense. But by exploring a smaller one – the role of grazing ruminants in contributing to, or mitigating climate change – we hope to contribute some of the sub-structural knowledge we need if the big question is, ultimately, to be answered.

While this is a long and detailed report, it is accompanied by shorter summaries in different formats. We hope its conclusions will reach a wide audience, including those – policy makers, the food industry, civil society and other opinion formers – who ultimately have the power to shape the future of the food system.

Introduction

Ruminants get a bad press in the environmental literature, the popular media and, increasingly, the public imagination. They emit large quantities of methane, use vast tracts of land, and are held responsible for a host of environmental ills, most notably climate change, deforestation and biodiversity loss, as well as the pollution of soils, air and water. Beef is bad, it is argued.

Box 1: What are ruminants?

The word 'ruminant' comes from the Latin ruminare, which means 'to chew over again'.

Ruminants are mammals which are able to obtain nutrients from ligno-cellulosic rich plants by fermenting them before they are digested, with the aid of microbes in their specialised, four-compartmented stomach. The animals begin by partly chewing a saliva-lubricated mass of grass or vegetation. They swallow it, and the food passes into the large rumen. Muscle action there churns it with microbes, which then begin fermenting the food. When microbes break down and digest carbohydrates they generate fatty acids, nutrients which the ruminant can absorb into its blood through the rumen walls. During this metabolic process, hydrogen is produced, which is subsequently incorporated into methane (CH_4) which the ruminant eructs or burps – this is enteric fermentation.

This whole process has the effect of breaking food down into clumps, or cuds, both in the rumen and in the second compartment, the reticulum. The animal then regurgitates these cuds, chews again, swallows again and so forth. This repeated process creates a larger surface area for the microbes, who continue digesting the food and extracting nutrients. Once this process is complete, the nutrients pass through to the third stomach compartment, the omasum, which breaks down the nutrients some more, and finally the abomasum which functions much like a monogastric stomach, using enzymes to further digest the food. Note that fermentation in the hindgut (i.e. intestines) also contributes a little (generally less than 10%) to enteric methane emissions.

The advantage of this process is that ruminants are able to digest coarse cellulosic material such as grass, husks, stalks and so forth, which monogastric animals such as pigs, poultry and people cannot. The disadvantage is of course that they generate methane emissions.

There are, of course, many kinds of farmed ruminant animals, from cattle through to sheep and goats as well as minor species, such as llamas and camels. Cattle are however by far the most important species as to numbers, impacts and food output.

If beef (and, logically, milk) is bad, then several courses of action present themselves. One approach, generally favoured by policymakers and intergovernmental institutions, is to manage the damage. Since growth in the livestock sector is seen to be not only inevitable but desirable for the economy, jobs and nutrition, then the obvious way forward is to make ruminant products a little less bad, environmentally speaking. This is to be achieved via intensification: for example by improving feed crop and animal breeding, optimising feed formulations, and by reducing the amount of land animals use, either by confining them in production units or by intensifying pastures.[1] The extensively reared ruminant – which predominantly feeds on grass – is the most problematic of creatures since its productivity is low in relation to the land and feed it requires, and the volume of gases it emits per unit of meat or milk output is great. So, if we are to eat ruminant products, let them be the products of intensive systems. Better still, the growing preference for monogastric products (pork and poultry meat, and eggs) is to be encouraged since these animals emit much less methane and use far less land per unit of livestock product over their production cycles.

An alternative approach, which tends to be popular with the environmental and animal rights movements is to cut back on eating animal products altogether. If we humans were to eat plants directly, rather than first passing them through an animal, less land and fewer inputs would be needed to feed our growing global population numbers and – crucially – fewer climate-warming gases would be emitted. Grazing lands now used for ‘inefficient’ livestock production could be used for bioenergy production or afforested or rewilded – yielding carbon sequestration and other environmental benefits. Many additional arguments (not discussed in this report – see Box 2) are often brought to bear around the unhealthiness of meat, the abuse of farmed animals and so forth.

Let us eat pigs, or poultry, or plants… but not everyone agrees with these representations of the situation nor with the solutions proposed. While they vary widely in their views, a sizeable sub-section of the research and civil society communities fear that simplistic conclusions of the ‘all beef is bad, and extensively reared beef is the worst’ variety may lead to perverse outcomes.

For these stakeholders, the first approach, with its industrialised vision of environmental sustainability, is deeply problematic for diverse reasons, including for its impacts on animal welfare, the concentrated corporate power structures it embodies and perpetuates, the large amounts of human-edible feed that are used, its failure to take account of poor people and their production systems and perhaps because of a more visceral unease with the ‘unnaturalness’ of these production systems. As to the second approach, stakeholders of the third perspective argue that people are not going to stop eating animal products any time soon. The nutritional importance of these foods needs recognising too; and while the affluent may certainly need to eat less, for this third set of stakeholders the priority is to ensure that whatever we do eat is ‘better’,[2] across various dimensions of sustainability. Those within the international development community, who share at least aspects of these views, also place strong emphasis on the importance of livestock production as a provider of livelihoods –

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1 Gerssen-Gondelach, S. J., Lauwerijssen, R., Havlík, P., Herrero, M., Valin, H., Faaijd, A. and Wicke, B. (2017). Intensification pathways for beef and dairy cattle production systems: Impacts on GHG emissions, land occupation and land use change, *Agriculture, Ecosystems & Environment*, 240(1), http://dx.doi.org/10.1016/j.agee.2017.02.012.

2 Eating Better, n.d. Q&A [online]. http://www.eating-better.org/learn-more/q-a.html (accessed 11.7.17).

particularly for poor people in low income countries, but also among rural communities in the affluent West. The reality is that some of the world's most vulnerable people, including the world's 200 million pastoralists,[3] rely on animal keeping for their living: as a source of income; for the nutritional value of meat, milk and eggs in diets that lack diversity (of particular importance for children and pregnant women); for their traction, and as one of many strategies people adopt for spreading risk and maintaining financial security. Among mixed crop-livestock systems – that still produce the dominant share of meat and milk output (Section 1.2) – livestock recycle nutrients and organic manure within the farm system. The centrality of livestock keeping – and of meat or milk consumption – to traditional cultures and identities may also be highlighted.

This is where the grassfed ruminant starts to play a central but contested role in discussions. Most academic studies conclude that ruminant products are the most emissions-intensive of all animal products, and within ruminant production systems, extensively reared are the worst. But advocates of the third perspective find this conclusion too simplistically based on a narrow set of metrics – such as GHG emissions per unit of meat or milk output. They highlight instead the metabolic miracle that is the rumen, pointing out that cattle and other ruminants can be reared on land unsuited to other food-producing purposes and on by-products, and that in mixed farming systems the animals recycle nutrients and re-fertilise soils with their dung, thus fostering a new generation of crops and pasture. In other words, this approach to animal husbandry prioritises the *effectiveness* of resource use, rather than the simple 'efficiency' of its use,[4] and has variously been called a 'livestock on leftovers,' 'ecological leftovers', 'default livestock,' or 'consistency' strategy.[5,6,7]

A more extreme position – drawn particularly from the ranching and alternative agriculture communities – goes further still to argue the case for ruminant production on the very narrow terms of GHG emissions alone.[8,9,10] In other words, leaving aside claims about the broader environmental and societal dimensions of grazing ruminant production, these advocates argue that traditional wisdom has got its GHG sums wrong , because it has only part-completed the equation. Ruminants may emit GHGs, but by grazing untilled land, ruminants not only keep carbon from being released in well-managed systems, they even help sequester it. Additionally their manure acts

3 Rota, A. and Sperandini, S. (2009). Livestock and pastoralists, Livestock Thematic Papers. Rome, Italy.

4 Garnett, T., Röös, E. and Little, D. (2015). *Lean, mean, green, obscene…? What is efficiency, and is it sustainable?* Food Climate Research Network, University of Oxford.

5 Garnett, T. (2009). Livestock-related greenhouse gas emissions: impacts and options for policy makers, *Environmental Science & Policy*, 12(4), pp. 491-503.

6 Fairlie, S. (2010). *Meat: a Benign Extravagance*, Permanent Publications, UK.

7 Schader, C., Muller, A., El-Hage Scialabba, N., Hecht, J., Isensee, A., Erb, K.-H., Smith, P., Makkar, H.P.S., Klocke, K., Leiber, F., Schwegler, P., Stolze, M. and Niggli, U. (2015). Impacts of feeding less food-competing feedstuffs to livestock on global food system sustainability, *Journal of the Royal Society Interface,* 12(113).

8 Sustainable Food Trust (2014). An open letter to George Monbiot [online]. http://sustainablefoodtrust.org/articles/george-monbiot-allan-savory/ (accessed 8.6.17).

9 Sustainable Food Trust (2015). What role for grazing livestock? [online]. http://sustainablefoodtrust.org/articles/role-for-grazing-livestock-red-meat/ (accessed 8.6.17).

10 Land Stewardship Project (2016). Carbon, Cattle & Conservation Grazing [online]. http://landstewardshipproject.org/posts/838 (accessed 8.6.17).

as a substitute for energy intensive synthetic fertiliser inputs in mixed crop-livestock systems, also leading to avoided emissions. As such, grazing systems are an essential aide to achieving the 'negative emissions' we need if we are to meet our global climate goals. A distinction should, moreover, be made (they argue) between the climatic effects of fossil fuel-generated carbon dioxide and those of biogenic methane emissions – particularly since wild ungulates also produce methane, and so our farmed ruminants are simply replacing those that we have hunted to extinction.

Indeed, a move away from grass-based ruminant production could (the argument continues) actually make climatic matters worse rather than better. The global shift towards diets rich in commodity oils, grains and sugars will trigger the ploughing of pastures with all the attendant ills – in the form of soil carbon release and biodiversity loss – that this entails. Moreover, it is the consumption of arable-based foods rather than of 'wholesome' animal products, that drives obesity and micronutrient deficiencies.[11,12,13,14] Eating relatively *more* grassfed rather than *less* grassfed beef is in fact, not just compatible with, but essential to achieving a low emitting, healthy sustainable food system – and little or nothing is said about the need to cut down on the absolute quantities we consume.

Clearly, this short overview oversimplifies matters, and there will be many gradations of opinion, but it does delineate the parameters of what is often a heated and polarising debate.

The bones of the dispute are summarised in Table 1.

The purpose of this report is to investigate a subset of these arguments in more detail: specifically the role of ruminants in grazing systems in the net GHG balance. Do 'grassfed' systems hold potential to help address our climate problems, or is their overall contribution damaging?

There are of course many other ethical, nutritional and livelihood related arguments that can and should be explored to gain understanding of the benefits and costs of grazing systems (see Box 2), but this report limits itself just to the question of GHG emissions and removals since the climate question is central to discussions on the sustainability of food systems – and complex enough as it is. A separate report will be produced which assesses the implications of grassfed ruminant production for biodiversity.

Chapter 1 provides some definitions – and shows the difficulty of so doing. It looks at the systems of animal production that exist, how much food they provide and how they are changing. What is a 'grassfed animal' or, more accurately, a grazing system? What is grazing land, how does it relate to grassland, and how much is there?

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11 Sustainable Food Trust (2017). Understanding fats [online]. http://sustainablefoodtrust.org/articles/understanding-fats/ (accessed 11.7.17).

12 Young, R. (2014) The fat of the land: Eating red meat [online] http://sustainablefoodtrust.org/articles/red-meat/ (accessed 11.7.17).

13 Paleo Leap (2017). Paleo, Meat, and the Environment [online]. https://paleoleap.com/paleo-meat-environment/ (accessed 11.7.17).

14 Rodgers, D. (2016). Eating Paleo Can Save the World [online]. https://robbwolf.com/2016/01/13/eating-paleo-can-save-the-world/ (accessed 11.7.17).

Table 1: The bones of the dispute.

	Area of contention	Argument	Counterargument
1 (see Chapters 2 & 3)	The balance between greenhouse gas (GHG) emissions and removals.	Ruminants are a major source of GHG emissions, particularly carbon dioxide (CO_2) via land use change, methane (CH_4) and nitrous oxide (N_2O); any soil carbon sequestration arising is small, uncertain, time-limited, reversible and difficult to verify.	Ruminants in well-managed grazing systems can sequester carbon in grasslands, such that this sequestration partially or entirely compensates for the CO_2, CH_4 and N_2O these systems generate.
2 (see Chapter 4)	The importance of methane as a contributor to the climate problem. The role of the nitrogen cycle.	CH_4 is a particularly potent GHG and ruminants are significant contributors Livestock are a source of N_2O, a highly potent GHG. More broadly, efforts to sequester carbon risk incurring increases in nitrous oxide emissions. Livestock do not add any new nutrients to the land, but rather introduce an additional very leaky cycle.	CH_4 has a short life span; CO_2 from burning fossil fuels is a greater concern for permanent warming and shifts the balance of culpability onto CH_4 'efficient' but fossil-fuel dependent intensive systems Historically wild ruminants roamed on many grasslands, producing CH_4. Farmed ruminant emissions need to be seen in the context of this historical baseline count. Livestock play a vital role in recycling nutrients – including nitrogen – and make them more available for plants to take up, thus fostering a new generation of plant growth.
3 (see Chapter 5)	Grazing systems and their role in land use (LU) and land use change (LUC) as compared with intensive monoculture crops and monogastric systems; the historical role of ruminants on the land	Ruminants in grazing systems occupy a large land area and have historically caused LUC and associated above/below ground carbon release. Plant-based diets and grainfed intensive livestock systems use less land and so cause less damaging land use change.	Many grasslands are the natural climax vegetation and not suited to cropping. Crop production – for human food and intensive animal feed – increasingly drives land use change, and encroaches onto carbon-storing pastures.

The subsequent four chapters form the heart of the report. Chapter 2 briefly summarises mainstream scientific understanding about the livestock sector's contribution to GHG emissions, focusing particularly on ruminants and those reared in grazing systems. This sets the scene for Chapters 3, 4 and 5 which examine the evidence that stakeholders use to counter this mainstream narrative of high ruminant-attributable emissions.

Box 2: Livestock and the bigger picture – what this report does not focus on

This report narrowly focuses on one question: the role of domestic grazing ruminants in the net greenhouse gas balance. But of course the rearing of livestock, both those in grazing systems and those that are not, positively and negatively affects people, society, the economy, and other aspects of the environment, as well as the animals themselves in a huge number of other ways. We list here just some of the important issues this report *does not* explore:

- Human nutrition, animal source foods and the multiple pathways linking production to consumption and nutritional status
- Health: zoonotic diseases (endemic and epidemic), food safety, water pollution, and antibiotics resistance
- Gender and the links with (different types of) livestock keeping, markets, income and household spending, nutrition and intra-household distribution of food
- Jobs, livelihoods, economic development, power and gender: including production, financing, risk spreading, marketing, intra-household distribution, and changing structures of production
- Culture, identity and tradition: ideas about the mutability/inalienability or otherwise of these
- Animal ethics: animal rights, animal welfare
- Biodiversity and its extrinsic and intrinsic value
- Hydrology: land use and water catchments, water footprints, and water pollution
- Other forms of environmental pollution

Each one of them is itself the focus of detailed, often contradictory research and of claims, counterclaims and contestations. 'Facts' are quoted and assertions made which do not bear closer scrutiny or at best need nuancing and qualifying. To do justice to any one of these issues would require analysis at least as lengthy as what we have undertaken here for greenhouse gases – which is why we have chosen to limit our scope.

Chapter 3 considers if and how grazing systems could sequester soil carbon and therefore contribute to GHG mitigation, and if so by how much. Chapter 4 examines methane and nitrous oxide emissions – both of which make important contributions to the overall carbon footprint of ruminants. First, it asks whether methane's shorter atmospheric life span should modify our assessment of ruminants' contribution to climate change; next, it considers how the dynamic interactions between the carbon and nitrogen cycles further affect judgements about the net potential afforded by soil carbon sequestration and the role of ruminants in recycling nutrients within the system. Chapter 5 looks at past, present and emerging dynamics of land use change to assess the respective roles of grazing animals *versus* intensive food and feed crop production in contributing to above- and below-ground carbon release. Chapter 6 draws some conclusions and offers some suggestions for further research.

1. Grassfed cattle, grazing lands and their variants: definitions and trends

Key points

- Ruminants are animals that can digest coarse cellulosic material, such as grass. A consequence of this is that they also generate methane emissions.
- Ruminants can be reared in many different systems across the world but they are most commonly reared in mixed crop-livestock systems, followed by grazing systems.
- However there is huge variation within these system classifications, making hard and fast definitions difficult. This also makes it hard to draw conclusions about the merits of one system over another, unless hedged with caveats and qualifiers.
- There is no official definition of 'grassfed' beef or milk.
- Ruminant milk and meat contributes 13 g protein/person/day – about half of the world's terrestrial animal protein supply (27 g protein/person/day), or just over a third of animal protein supply if sources from aquaculture are also included.
- Grazing systems currently account for only a fraction of overall animal protein supply globally at about 1 g/person/day. The potential output could be higher though and is discussed further in Chapter 5.
- Grasslands play a significant role in mixed crop-livestock systems as well: as such the contribution of grasslands to human protein supply is higher but difficult to estimate, and complicated by the fact that animals in these systems may also be fed grains as well as agricultural by-products.
- Grasslands are among the largest ecosystems in the world, occupying between 20-47% of the land area. The large range reflects, among other things, difficulties of obtaining accurate data, different methodologies (remote sensing versus ground surveys) and different ways of defining and distinguishing between different vegetation types.
- Distinctions are generally made between natural grasslands (also referred to as rangelands), semi-natural grasslands and improved grasslands or pastures.
- Livestock systems are transforming across the world, with a strong shift towards intensification and particularly rapid growth in pig and poultry production. These changes have major implications for future livestock emissions, both those that are direct and those that arise from land use change.
- Notwithstanding these rapid transformations, traditional, often subsistence, livestock production continues in many low income countries.

Various words tend to be used over and again in discussions about animal farming: intensive, extensive, grassfed, grainfed, industrialised. For the most part, they are used without being defined, the assumption being that the meaning is clear.

Yet these words have no hard and fast definitions; the boundary between a system viewed as intensive versus extensive may shift according to agro-ecological zone, livestock type, over the life course of the animal itself and of course what it is one is being intensive or extensive *with*. Is it fossil fuels? Technology? Labour? Land? (Garnett *et al.* 2015 provide a more detailed discussion).[15] This fluidity makes it hard to form categorical judgements about the merits of one system over another, unless bounded with more specific detail.

Nevertheless, a number of formal classification systems have been developed, which are used by organisations such as the FAO. This chapter starts with a short overview of the one that is most commonly used. It then goes on to focus on the land base that supports 'grassfed' beef and milk production: the grazing lands themselves. What are they, how much of them are there, how are they changing and what do these changes mean for our understanding of the environmental role that grassfed animals play?

1.1 Some livestock system classifications

Livestock can be reared in many different systems. Various attempts have been made to provide classifications, which may differentiate according (for example) to: the extent to which livestock are integrated with crop production, the animal type, feed source or agro-ecological region.[16,17]

Seré and Steinfield's[18] method of categorisation is perhaps the most well known and most frequently adopted (Table 2). These authors categorise ruminant and non-ruminant livestock production into 11 main systems which fall broadly into the following three main categories:

Mixed crop-livestock systems: Most of the ruminant meat and milk produced globally comes from these systems, but as a category it is the least precise. Mixed systems are those in which either less than 90% of the dry matter[†] fed to animals comes from grass (with the remainder variously coming from crop by-products, residues,[§] ley crops and feed grains), or (incorporating an economic dimension here) more than 10% of the total value of production comes from non-livestock farming activities. Clearly, a farm where livestock obtain 89% of their feed from grass and 11% from commercially prepared feeds; and one where 89% of the feed source consists of commercial feeds and crop residues and only 11% from grass will be hugely different. Both, though, are technically mixed systems.

[†] **Dry matter** is what remains after the water is evaporated out of a feed. Fresh grass has high water content and will have a lower percentage of dry matter than an equivalent weight of dry feed. Dry matter is an indicator of the amount of nutrients available to the animal in a feed.

[§] **Residues** are the forage remaining on the land after harvest.

[15] Garnett, T., Röös, E. and Little, D. (2015). *Lean, mean, green, obscene…? What is efficiency, and is it sustainable?* Food Climate Research Network, University of Oxford.

[16] Steinfeld H., Wassenaar T., and Jutzi S. (2006). Livestock production systems in developing countries: status, drivers, trends. *Rev. sci. tech. Off. int. Epiz.*, 25 (2), pp. 505-516.

[17] Seré C. and Steinfeld S. (1996). World livestock production systems: current status, issues and trends. FAO Animal Production and Health Paper 127. Food and Agriculture Organisation, Rome.

[18] Seré C. & Steinfeld S. (1996). World livestock production systems: current status, issues and trends. FAO Animal Production and Health Paper 127. Food and Agriculture Organisation, Rome.

Moreover, integration with the cropping system can occur at different spatial scales. Animals may be reared on a farm that grows various crops and rears different animal types; or a farmer may specialise in one species only and source feed from neighbouring farms. But even if the farm itself is mixed, the animals may well additionally consume feed inputs that come from distant regions. Rarely will the farm operate an entirely closed nutrient loop: feeds or fertilisers will have been produced elsewhere, potentially causing nutrient deficits in one area and surpluses in another. Knowing these details is essential if one is to draw informed conclusions as to the environmental impacts.

Mixed systems may be subdivided further into rainfed or irrigated systems. Mixed temperate-region farms tend to be more productive than those in arid areas, partly because of climate and partly because wealthier countries, who are usually located in temperate zones, generally use more inputs.

Table 2: Definitions of grazing, mixed and landless systems (Seré and Steinfeld, 1996)

Mixed farming systems	Solely livestock systems	
Either more than 10% of the dry matter fed to animals comes from crop by-products or stubble,[†] or more than 10% of the total value of production comes from non-livestock farming activities.	More than 90% of dry matter fed to animals comes from rangelands, pastures, annual forages[§] and purchased feeds and less than 10% of the total value of production comes from non-livestock farming activities.	
	Landless livestock production systems	**Grassland-based systems (also called grazing systems)**
	Less than 10% of the dry matter fed to animals is produced on the farm, and annual average stocking rates are above 10 temperate livestock units[‡] per hectare of agricultural land.	More than 10% of the dry matter fed to animals is produced on the farm and annual average stocking rates[ƒ] are less than 10 temperate livestock units per hectare of agricultural land.

Landless systems: Often referred to as grainfed, intensive, industrialised or confined systems, these attract much criticism by environmental and animal welfare groups – but for the livestock industry they represent the apotheosis of environmentally efficient farming. Landless farms are livestock only systems in which less than 10% of the dry matter fed to animals is farm-produced and annual average stocking rates are above 10 temperate livestock units per hectare. Feed is commercially prepared and consists of cereals and oilseed based proteins. However even intensively reared ruminants may spend the first 6–8 months of their life on grass, and once confined may be fed grass in the form of silage. Animals in mixed systems may also be reared in confinement and can be found at all scales of production.

Grazing systems: These, of course, are specific to ruminants only. In these systems more than 90% of dry matter fed to animals comes from rangelands, pastures, annual forages and purchased feeds and less than 10% of the total value of production comes

† The **stubble** is the basal portion of the stems and leaves of plants that are left standing after harvest.

§ **Forage** is the edible part of plants, other than separated grain, which provides feeds for grazing animals or which can be harvested as feed.

ƒ A **stocking rate** is the relationship between the number of animals and the total area of the land in one or more units utilized over a specified time. Where needed, it may be expressed as animal units or forage intake units per unit of land area over time (animal units over a described time/total system land area) (Allen *et al.*, 2011).

‡ A **livestock unit** (e.g. Livestock Unit, Temperate Livestock Unit, Tropical Livestock Unit) is a reference unit that facilitates the aggregation of livestock from various species and age, via the use of specific coefficients established initially on the basis of the nutritional or feed requirement of each animal type. These coefficients may vary by region, but a beef animal is about 0.7 and a sheep or goat about 0.1 Tropical Livestock Units (TLU). The TLU of a dairy cow is higher than both of these since she has higher nutritional requirements. So, for example 1 cow (TLU=0.7) and 4 sheep (TLU=0.1) are equivalent to 1.1 Tropical Livestock Unit (1*0.7+4*0.1=1.1).

from non-livestock farming activities. The remaining 10% of the diet can come from supplementation. For example in the dry season animals may be given hay, molasses or other supplements.

This broad definition encompasses huge variations – from animals grazing on sparse scrubby grass in sub-Saharan Africa, through to Irish cattle reared on lush pastures that have been sown with a grass-clover mix and boosted with fertilisers. As noted, livestock may start in a grazing system and be finished in a confined unit. In some climates, animals need to be kept indoors for some parts of the year.

What about 'grassfed'?

There is much popular noise about 'grassfed' but no official government standards exist – while the USDA did develop one it revoked it in 2016.[19] Some private labels operate but they vary considerably in their rigour. The UK's Pasture for Life Standard[20] is at the stricter end, requiring that animals be 100% grazed, prohibiting the use of supplementary grains and proteins, and requiring that wildlife and environmental conservation measures are in place. Use of artificial fertilisers and other inputs while permitted is discouraged. The American Grassfed Association standards are similar, but do not mention environmental stewardship requirements.[21] Under Australia's Pasturefed Cattle Assurance System, animals must be reared on pasture but hormones and growth promoting antibiotics are permitted provided mention is made on the label.[22] Sweden has a third-party certification scheme, IP Sigill Naturbeteskött (Semi-natural pastures)[23] – this requires that 50% of the land used for grazing is semi-natural pastures (as opposed to grazing on cropland) and that 70% of the feed, by dry matter weight, is forage. Organic production systems also place constraints on the types of feed that may be given to ruminants and may specify a mininum proportion of grass in the diet.

1.2 How much meat and milk do these different livestock systems produce?

Cattle, buffalo, sheep and goat production yields some 26% of overall global terrestrial meat output, expressed in tonnes. Pig and poultry meat contributes the remaining three quarters, in roughly equal amounts.[24]

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19 National Sustainable Agriculture Coalition (2016). USDA Revokes Grass Fed Label Standard [online]. http://sustainableagriculture.net/blog/release-usda-revokes-grass-fed-label-standard/ (accessed 11.7.17).

20 Pasture for Life Association (2016). Certification Standards For Ruminant Livestock. http://www.pastureforlife.org/certification/the-pasture-for-life-standards/ (accessed 11.7.17).

21 American Grassfed, n.d. Our Standards [online]. http://www.americangrassfed.org/about-us/our-standards/ (accessed 11.7.17).

22 Cattle Council of Australia, n.d. What is PCAS? [online]. http://www.pcaspasturefed.com.au/ (accessed 11.7.17).

23 Sigill Kvalitetssystem AB, 2014. CERTIFIERAT NATURBETESKÖTT [online]. http://sigill.se/IP-STANDARD/CERTIFIERING-ENLIGT-IP/CERTIFIERING-ENLIGT-IP/CERTIFIERAT-NATURBETESKOTT/ (accessed 7.11.17).

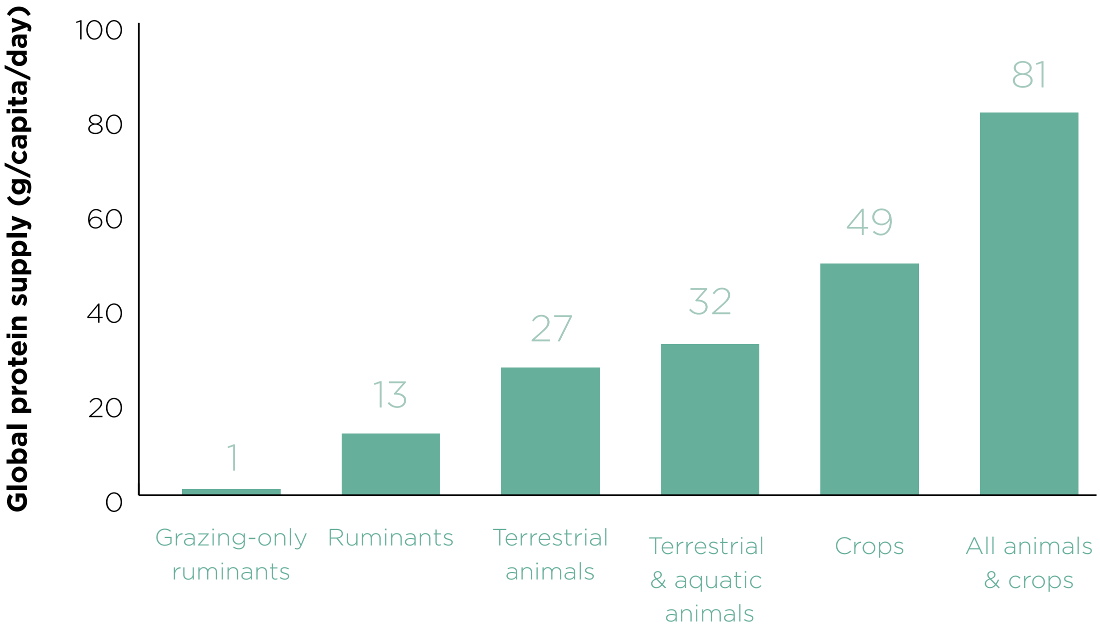
24 For year 2013 – FAO (2017). FAOSTAT [online]. http://www.fao.org/faostat/en/ (accessed 13.5.17).

Of course, ruminants – and especially cattle and buffaloes – also supply milk. If the food value of milk is included, the contribution from ruminants – reared in all systems – increases to a much more significant 47% of terrestrial animal protein. If aquatic protein is considered too, the protein provided by ruminants falls to 39% of the animal source total (Figure 1).[25]

Animal-source protein (all sources) constitutes about 40% of overall human protein intakes; plant sources in fact contribute the dominant share.[†]

† Animal and plant-based protein differ in their composition, and meat and milk additionally supply many other micronutrients that are less abundant or bioavailable in plants. At the same time, plants provide some additional nutrients that animal source foods do not. These points mean that simple comparisons between the nutritional offer of plant and animal proteins do not do justice to the reality. The subject begs for a long and important discussion about the relative merits of animal versus plant sources of nutrition and how these should be factored into strategies aimed at optimising land use and reducing GHG emissions. That discussion, however, sits outside the scope of this report.

Figure 1: Contribution of ruminant and other sources of protein to total human protein supply. Data from FAO (2017) for year 2013[26]



Note that the difference between food supply and actual intakes may be very large, because losses and waste occur throughout the food chain.

Most of the ruminant milk and meat (by weight) is produced in crop-livestock mixed systems. But as noted above, since these mixed systems vary so widely in their use of feeds and inputs, this observation is not especially informative.

As to grazing systems, very recent data are not available, but in the year 2000 they yielded about 13% of the cattle meat and 6% of the cattle milk by weight – and a higher share in the case of small ruminants (Table 3). This works out at about 1 g of protein per person per day – daily availability from all terrestrial animal sources is 27 g. The contribution of grazing systems to total food production is likely to be smaller still today given the move towards intensification, although they remain critically important for people living on marginal lands for whom grazing animals are a vital source of nutrition and livelihoods. It is important to note that since grass is also fed to animals in mixed crop-livestock and to an extent in other systems, the contribution of grasslands

25 For year 2013 - FAO (2016). FAOSTAT [online]. http://www.fao.org/faostat/en/#data/FBS (accessed 5.17.16).

26 *Ibid.*

to global food production is higher than this figure suggests – although that said, the grassland contribution in mixed systems is hard to estimate as the animals additionally consume grains as well as agricultural residues. This makes it hard to disentangle the nutritional contribution that grass makes compared with these other feed inputs.

How much solely grassfed meat or milk could *potentially* be produced is a different question and discussed further in Section 5.

Table 3: Global production of meat and milk from large ruminants (beef and dairy cattle), small ruminants (sheep and goats), pigs and poultry by production system, and by TLU: Tropical Livestock Unit

		Total	Grass-based livestock systems	Mixed crop-livestock systems	Other	Landless livestock systems
Large ruminants	**Animal number** (million TLU, % of total)	956.7	174.6 (18%)	542.1 (57%)	181 (19%)	59 (6%)
	Milk (Mt/yr, % of total)	570	33 (6%)	397 (70%)	95 (17%)	45 (8%)
	Meat (Mt/yr, % of total)	68	9 (13%)	44 (64%)	11 (16%)	5 (7%)
Small ruminants	**Animal number** (milllion TLU, % of total)	181.2	59.2 (33%)	94.6 (52%)	19.1 (11%)	8.4 (5%)
	Milk (Mt/yr, % of total)	21	4 (22%)	12 (58%)	3 (13%)	1 (7%)
	Meat (Mt/yr, % of total)	13	4 (29%)	7 (56%)	1 (10%)	1 (6%)
Pigs	**Animal number** (million TLU, % of total)	199.3	-	-	74.5 (37%)	124.8 (63%)
	Meat (Mt/yr, % of total)	91	-	-	22 (24%)	69 (76%)
Poultry	**Animal number** (million TLU, % of total)	159.5	-	-	69.5 (44%)	90 (56%)
	Eggs (Mt/yr, % of total)	149	-	-	14 (9%)	135 (91%)
	Meat (Mt/yr, % of total)	96	-	-	12 (13%)	84 (87%)

Data from Herrero et al. *(2013). Livestock production systems as defined by Seré and Steinfeld (1996), first mapped by Thornton* et al. *(2002) and updated by Robinson* et al. *(2011).*[27]

[27] Herrero, M., Havlík, P., Valin, H., Notenbaert, A.M., Rufino, M.C., Thornton, P.K., Blümmel, M., Weiss, F., Grace, D. and Obersteiner, M. (2013). Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. *Proc. Natl. Acad. Sci. U. S. A.*, 110, pp. 20888–93. doi:10.1073/pnas.1308149110

Seré, C. and Steinfeld, H. (1996). *World livestock production systems: Current status, issues and trends*, FAO Animal Production and Health. Rome, Italy.

Thornton, P.K., Kruska, R.L., Henninger, N., Kristjanson, P.M., Reid, R.S., Atieno, F., Odero, a N. and Ndegwa, T. (2002). *Mapping Poverty and Livestock in the Developing World*. International Livestock Research Institute, Nairobi.

Robinson, T.P., Thornton, P.K., Franceschini, G., Kruska, R.L., Chiozza, F., Notenbaert, A., Cecchi, G., Herrero, M., Epprecht, M., Fritz, S., You, L., Conchedda, G. and See, L. (2011). *Global livestock production systems*. Rome.

1.3 Grasslands, grazing lands and a few variants – what are they?

The defining feature of grassfed beef (and of course milk) is that the animal is reared on grass. But many words are used to refer to large grassy areas: grasslands, rangelands, pasture, and grazing land. These have different, sometimes overlapping meanings, and they differ in their environmental qualities and impacts.

While definitions abound, broadly speaking, **grasslands** are ecological communities dominated by grasses with little to no tree or shrub cover. Some grasslands are natural – that is grass is their natural climax vegetation – while other grasslands have been created from other forms of vegetation, notably forest.

As to the distinction between **grasslands** and **grazing lands**, while the words are often used interchangeably, arguably the former refers to the land's vegetative characteristics and the latter to its use value, whether existing or potential, to humans. While humans use grasslands for grazing, not all grasslands are grazed by domesticated animals. Some may be protected – grazing is prohibited – and others located in regions that simply cannot support them. In some parts of the world domestic animals will share grazing lands, sometimes uncomfortably, with wild herbivores.

Grasslands are among the largest ecosystems in the world, occupying between 2600 to 6100 Mha (Godde *et al.*, 2017) [28] or about 20–47% of the earth's land area as estimated by FAO (2017).[29] Of this total, one analysis suggests that about 2,600 Mha – the lower end of the estimates – are grazed by domestic animals (Henderson *et al.*, 2015).[30] Clearly the range of estimates is huge, reflecting the difficulties encountered in making assessments of this nature. Regions and countries differ in their ability to provide accurate data and they use different methods for estimating the land area – some may use remote sensing, others ground data, and others use both. They may also define land cover in different ways: a mixture of grass and trees may be defined as woody grassland, or as grassy woodland. The land use is also constantly in flux: sometimes grazing land may be converted to cropping, or vice versa depending on growing conditions, market prices and policies. Importantly, many of the aggregate estimates given in the literature are based on very old data, and since then the processes of expansion, disappearance, intensification, abandonment and degradation have been playing out in different ways in different parts of the world.[31] Consequently, the situation today could be quite different.

Grasslands tend to be categorised into those we consider 'natural', those that are 'semi-natural' and those that are 'cultivated' or improved; but these distinctions are somewhat arbitrary.

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28 Godde, C., Garnett, T., Thornton, P., Ash, A. and Herrero, M. (2017). Grazing systems expansion and intensification: drivers, dynamics, and trade-offs. *Global Food Security*. (under review)

29 FAO, 2017. FAOSTAT [Online]. http://www.fao.org/faostat/en/ (accessed 13.5.17).

30 Henderson, B., Gerber, P.J., Hilinski, T.E., Falcucci, A., Ojima, D.S., Salvatore, M. and Conant, R.T. (2015). Greenhouse gas mitigation potential of the world's grazing lands: Modeling soil carbon and nitrogen fluxes of mitigation practices. *Agric. Ecosyst. Environ.*, 207, pp. 91-100. doi:10.1016/j.agee.2015.03.029

31 Godde, C., Garnett, T., Thornton, P., Ash, A. and Herrero, M. (2017). Grazing systems expansion and intensification: drivers, dynamics, and trade-offs. *Global Food Security*. (under review)

Rangelands are generally understood to be **natural grasslands** composed largely of native wild vegetation. The terms are used interchangeably: both refer to lands whose climax or 'potential' vegetation would naturally be dominated by perennial grasses and whose species composition has not been altered to improve livestock productivity. Sometimes they hold protected status and may be managed to achieve ecological objectives, in which case grazing animals may sometimes be used for this.

That said, the idea of fixed 'potential vegetation' that changes only as a result of long term climatic fluctuations is itself problematic. Grasslands have indeed been around for millions of years, but the 'climax' vegetation at any particular point in time (forest versus grasslands, say) has swing-state status: the characteristics will depend not only on climate but on the actions of its 'consumers'- namely herbivores and fires – who were around before humans came onto the scene. Thus the 'natural' vegetation of a particular place changes over time (and sometimes rapidly) – and as Chapter 5 discusses, there is virtually nowhere on the earth's surface that has not in some way been modified by humans. Today, natural grasslands across the world are at risk. The threat is not just from the encroachment of agriculture (both cropping and pasture intensification) but also on occasion from afforestation programs, which are sometimes implemented in the mistaken belief that trees need 'restoring' to these landscapes.

If grazing lands were formed out of some prior vegetation a very long time ago, and if they are not subjected today to intensive management, they may be classed as **'semi-natural'**, to distinguish them from more intensively managed pastures and from 'natural' grasslands. While they tend to provoke a great deal of definitional debate, semi-natural grasslands can be broadly defined as 'habitats created by low-intensity, traditional farming, or, in some cases, the natural vegetation on poor soils or in exposed locations'.

The semi-natural grassland is, the authors of that description note, a very fluid habitat, which is amenable for conversion to (and from) arable land and to improved grassland through cultivation, re-sowing and fertiliser application. Variations in social and economic conditions have caused the area of grassland to fluctuate over centuries, especially through changes in the balance of arable and grassland areas. In a country such as the UK for example, if unmanaged, the land is likely to revert to a woodland state.

While these grasslands may not be 'natural' they are nevertheless valued: their presence is part of our cultural heritage and we may award them special protected status. Flora and fauna specific to these lands have often developed over years and with the abandonment or intensification of these lands (mainly by applying fertilisers) these species may be threatened in some regions. We like these habitats because we know them, which, however circular that might be, shows how difficult (and perhaps pointless?) it is to disentangle the human from the natural, at least in regions of the world, such as Europe, that have seen such a long history of human presence. There is of course, always the risk of the shifting baseline syndrome – that what we value is simply what we are familiar with, which is less diverse than what went before. Our understanding of biodiversity progressively diminishes.

Semi-natural grasslands today account for a fraction of the overall grassland area and in many parts of the world they are in decline. For example nearly half (47%) of the UK's grasslands have been lost since 1960, mainly to pasture 'improvement', with conversion to arable cropping running a close second. The drive to improve pastures is simply because semi-natural grasslands only support low stocking densities – a point worth noting given the claims made that well-managed grazing systems can support soil carbon sequestration and biodiversity gains and higher livestock numbers (see Chapter 5).

Pastures – sometimes called **'improved' grasslands** – are more intensively maintained and their productivity is boosted with inputs. These grasslands have been modified by sowing more nutrient rich grasses or legumes, and by using fertilisers, other amendments and sometimes irrigation so as to support more intensive livestock grazing. Improved pastures are species poor. Sometimes the grass is mowed to produce silage for winter feed. The animals themselves may receive feed supplements, in which case the dung they deposit loads the soil with externally produced nutrients. In some years, depending on the market price for grain, growing conditions, or specific agricultural policies, pastures may be ploughed for cropping or vice versa. The original climax vegetation may or may not have been grass.

Finally, and at the risk of definitional overload, the term 'grassland' encompasses many regional variants[32] – including Cerrado, Llanos, Campos, Pampa, Prairie, Steppe, Savanna, Tundra, and more (See Annex 1 for more details).

To summarise, there is much uncertainty and great variability in how much grazing land there actually is and how it is used. Chapter 5 highlights the implications of historical, current and future changes in land use on its carbon storage, sequestration and release potential.

1.4 How are livestock production systems, and meat and dairy consumption patterns changing?

The last thirty years have seen far reaching changes in animal husbandry practice, most evidently in OECD countries but increasingly also in the rapidly industrialising emerging economies and, to a more limited extent, in parts of some low income countries. The two most noteworthy features of these changes are the sheer growth in livestock productivity and, linked to this, in output. If this is true of the ruminant sector – the focus here – it is even more so of pig, poultry and farmed aquatic production, a point worth noting since their rise has affected the ruminant sector. These transformations have been driven by interacting and mutually reinforcing developments along the whole value chain, from agricultural practices themselves through to the way meat is sold and eaten.

It should be emphasised that these changes are not ubiquitous. For millions of people in low income countries, traditional mixed crop-livestock and pastoral systems remain central to people's livelihoods and sustenance and these ways of life are likely to continue for decades to come. What is more, in contrast with trends in affluent countries, productivity has generally stagnated or even fallen because of the many constraints and adversities that farmers face, including insecure access to land, climate

32 Allen, V.G., Batello, C., Berretta, E.J., Hodgson, J., Kothmann, M., Li, X., McIvor, J., Milne, J., Morris, C., Peeters, A. and Sanderson, M. (2011). An international terminology for grazing lands and grazing animals. *Grass Forage Sci.,* 66, pp. 2-28. doi:10.1111/j.1365-2494.2010.00780.

change, and lack of finance. The result is a marked, and growing, dichotomy between those who can access the market and benefit from the demand 'pull,' particularly from urban populations, and those who cannot.

Nevertheless the transformations that have been sweeping across many – if not all – parts of the world have triggered concern within the environmental and animal welfare movement, movements within which grazing advocates partially situate themselves. Modern, so-called industrialised livestock farming is everything that alternative agriculture / grazing advocacy stakeholders reject. Since understanding the arguments being made about the merits (or otherwise) of grassfed systems requires knowledge of exactly what the last thirty years have brought, the major developments that characterise the process of intensification are briefly described here.

1.4.1 Changes at the agricultural stage

On the animal production side, genetic innovations have created breeds that partition more of the nutrients in their feed into making products we want (lean muscle or milk) rather than those we do not; fat, or in dairy cows their own body muscle. Breeding advances in the cropping sector have likewise improved productivity massively, and made it possible and profitable to divert crops to feed animals as well as people. While ruminants still largely consume grass, agricultural by-products[†] and crop residues, to maximise their genetic potential they are also given grain and oilseed-based feeds formulated and supplied by transnational feed producers; and in some systems the animals may in fact be fed little grass at all.[33] Since commercial formulas are more digestible and less fibrous than traditional feeds, more energy is partitioned into increasing body weight or milk yields and less into the sheer process of digesting feed. As beneficial side effects, land requirements and methane emissions per unit of output are lower (see discussion in Chapters 4 and 5). There are costs too of course; animal health and wellbeing may be undermined, an important and now well-documented concern.[34]

Housing units have now been designed to enable high livestock densities, all managed by professionals with increasingly specialised expertise or roles. Since animals are more confined, they expend less energy on movement, which also increases feed conversion efficiencies.

The process of rearing animals is often divided into clearly compartmentalised stages, each serviced by a team of specialists – beginning with breeding; moving through pregnancy and gestation, the weaning stage; rearing, finishing, slaughter and further processing; and finally through to retail. These stages may be undertaken by individual companies, although sometimes corporations vertically integrate to achieve control of the whole value chain.

† **By-products** are the side products produced during the production of main product. They have some economic value but they are not the main purpose of the production activity. An example would be beet pulp and molasses, which are by-products of the sugar beet refining process and used for (among other things) animal feed. The term co-products is sometimes used to refer to one of several planned products deriving from a given production process and generally have significant or indeed equivalent economic value to one another. For example, soymeal and soy oil are both co-products of soy production and demand for either of these may be the determining driver of production in any given year. The terms may however be used inconsistently or interchangeably.

33 Mottet, A., de Haan, C., Falcuccia, A., Tempio, G., Opio, C. and Gerber, P. (2017). Livestock: On our plates or eating at our table? A new analysis of the feed/food debate. *Global Food Security*, in press.

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

1.4.2 Distributing and scaling up meat

This spatial disconnect at the agricultural stage has been spurred on by other labour-saving and output-enhancing technological innovations. Synthetic fertilisers substitute for and greatly overcome the limitations of organic fertilisers. Temperature-controlled housing, cold storage, better roads and other logistical developments all help get animals to the abattoir without them dying, and meat to market without it rotting. Because of these developments, the various stages of the animal value chain can be sited at great distance from one another and indeed be globally dispersed. The location of good transport infrastructure, good knowledge (labs, production regimes) or low land rents may be more important than proximity to markets. Technological developments have also reduced labour requirements, spurring on the population exodus to urban areas.

With all these modernising developments, the traditional role of ruminant livestock as users of non-arable land, consumers of by-products inedible to humans, and recyclers and returners of nutrients to the soil to support the next generation of crops dwindles. Pigs are no longer mobile dustbins, the recipients of household scraps and slop. The chicken is now a specialised animal: bred either for meat or eggs, not both. Livestock are no longer part of a larger agricultural metabolism. Viewed in terms of food output per quantity of land or resource input, traditional husbandry systems are simply judged to be not as productive.

There have of course been environmental consequences. The disconnect between crop and livestock production has been aided by, but also exacerbated by, the arable sector's reliance on synthetic fertilisers. Without a land base on which to spread manure, livestock's traditional role in nutrient recycling no longer applies and nutrient surpluses now cause pollution. Ammonia emissions in intensive pig and poultry production systems cause human and environmental harms. As systems intensify, their reliance on fossil fuels may increase. On the other hand, the methane intensity of ruminant production has declined, as has its aggregate land footprint – but as this last point prompts so many qualifiers and caveats, the need to address the question properly constitutes one of the primary motivations for writing this report. Finally, the increase in efficiencies has lowered the costs of production, enabling greater production and/or lower market prices. This means that the gains in environmental efficiency have been, and continue to be, outweighed by sheer increase in output.[35]

1.4.3 Eating meat: demand side changes

The stages beyond the farm gate have also seen major transformations that mirror developments in the food system more generally. These transformations interact dynamically with the many societal changes that are taking place and that have engendered shifts both in aggregate demand and in individual consumption patterns.

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[35] Smith, P., M. Bustamante, H. Ahammad, H. Clark, H. Dong, E.A. Elsiddig, H. Haberl, R. Harper, J. House, M. Jafari, O. Masera, C. Mbow, N.H. Ravindranath, C.W. Rice, C. Robledo Abad, A. Romanovskaya, F. Sperling, and F. Tubiello. (2014). *Agriculture, Forestry and Other Land Use (AFOLU)*. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

These changes include the global population increase, rising per capita wealth (with persistent exceptions) and urbanisation: more people means more mouths to feed; wealthier people can better afford highly desired foods, such as animal products; while the shift towards more urban life styles increases people's exposure to and consumption of meat-based foods in multiple forms – although the relationship between urbanisation and meat eating is complex.[36] Arguably, a fourth determinant of demand is this: technology-enabled increases in supply lowers costs, enabling animal products to be sold more cheaply and so stimulating demand – it perhaps also *requires* that demand be stimulated via marketing and other means, to provide a market for the increased output.

A particularly marked transformation along the whole value chain has been the rapid growth in the poultry sector – rapid both absolutely and in comparison with the slower pace of the ruminant sector.[37] Defined in its narrowest sense, chickens are 'efficient'. They do not 'waste' food energy by converting it into methane and as they have shorter breeding cycles and reproduction rates, selection for particular traits, such as yield, delivers results more quickly. More animal product (meat, eggs) can be obtained per given input of feed, land or water. Poultry also lend themselves to production in regions where land is scarce, making meat and eggs cheaper to produce and to buy. The sector's other winning card is that poultry meat offends no one's religious sensibilities except for strict Jains, some Buddhists and Hindus (although for the wavering, less so than other meat forms). Its bland taste makes it an adaptable ingredient for the fast food industry – but it also enjoys a reputation as a 'healthy' low fat meat. The ascendancy of the chicken is worth highlighting because while mainstream commentators note that the trend goes in the right direction – the higher feed conversion efficiency and lower carbon footprint of poultry will help us extricate ourselves from our environmental problems – from the perspective held by advocates of grassfed ruminant systems, the intensive chicken is the ultimate Orwellian doublethink. It consumes grain that could be eaten directly by humans, has no link to the cropping land base – and raises a host of other concerns, from its poor animal welfare record through to zoonotic disease and antimicrobial resistance risks.

1.4.4 The flip side

This, then, is the grand narrative of transformation, but the story also oversimplifies things. Despite the far reaching nature of these changes, about 600 million people in Sub-Saharan Africa and parts of Asia and Latin America still rely on traditional mixed crop-livestock farming and on pastoralism, and many of them live below the poverty line. The corollary of these modernising forces is, then, that they have left many behind: those livestock communities who lack access to inputs and infrastructure struggle with the daily reality of low yields, disconnection from markets and a rapidly dwindling pool of labour.

And although global forces are at work, much activity still takes place at the national or regional level. Most livestock products are not traded internationally and when

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[36] Satterthwaite, D., McGranahan, G. and Tacoli, C. (2010). Urbanization and its implications for food and farming. *Phil. Trans. R. Soc. B,* 365, pp. 2809-2820.

[37] Alexandratos, N. and J. Bruinsma. 2012. World agriculture towards 2030/2050: the 2012 revision. ESA Working paper No. 12-03. Rome, FAO.

they are, low and middle income countries are increasingly trading regionally among themselves. The traditional divide between rich and poor countries is also blurring as companies in emerging economies acquire companies that have a high income country origin or invest in agricultural land beyond their own territories. Meanwhile, the rich world is witnessing a rise in 'alternative' livestock farmers, who reject intensification in favour of 'traditional' pasture or grassfed systems of production, whether for ethical and environmental reasons, or because there is a niche but nevertheless growing market for their products.

2. How, and how much do ruminants contribute to GHG emissions?

Key points

- The livestock supply chain generates some 7.1 Gt CO_2-eq emissions, contributing to about 14.5% of global human-made GHG emissions.
- Cattle dominate global livestock emissions, accounting for about 65% of the total. Ruminants as a whole produce about 80% of total livestock-related GHG emissions.
- Grazing systems are responsible for 1.32 Gt CO_2-eq/yr or 20% of all emissions from livestock.
- There is, however, a huge range in the emissions intensity of animal production, with variations by production system, agro-ecological context and management regime.
- Diets high in animal, and especially ruminant, products tend to be more GHG intensive than those that are not.
- None of these figures factor in any potentially compensatory effects of soil carbon sequestration in grazing systems.

The Food and Agriculture Organisation[38] estimates that the livestock sector generates about 7 Gt CO_2-eq or 14.5% of global GHG emissions (Box 3 and Figure 2). This estimate is derived from a life cycle assessment approach and includes emissions from ruminant enteric fermentation, manure and feed production, livestock-induced land use change, and from post-farm energy use (Figure 2).

Other study estimates lie in the range of 5.6–7.5 Gt CO2-eq[39] with the differences lying in the scope of their analysis. For example, the IPCC, which reports on direct agricultural emissions for the sector as a whole, includes livestock's contribution via enteric methane as well as the methane and nitrous oxide emissions from urine and manure deposited on grazing lands or when stored. Feed related emissions are, however, not directly attributed to livestock, nor are emissions from land use change, or energy use – the latter being accounted for in an entirely separate chapter of the IPCC report. This naturally means that livestock emissions – from enteric fermentation and manure only – are estimated to account for a lower 5–7% of the anthropogenic total.[40]

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

39 Herrero, M., Henderson, B., Havel, P., Thornton, P.K., Smith, P., Wirsenius, S., Hristov, Gerrber, P., Gill, M., Butterbach-Bahl, K., Vain, H., Garnett, T. and Stehfest, E. (2016). Greenhouse gas mitigation potentials in the livestock sector, *Nature Climate Change*, 6, pp. 452-461.

40 Tubiello, F.N., Salvatore, M., Rossi, S., Ferrara, A., Fitton, N. and Smith, P. (2013). The FAOSTAT database of greenhouse gas emissions from agriculture. *Environmental Research Letters,* 8(1). http://iopscience.iop.org/1748-9326/8/1/015009.

Box 3: Facts, fiction, films and framings: who's who in the debate around livestock?

The past decade has seen a proliferation of studies focusing on livestock and the sector's environmental impacts: the most prominent being the FAO's 2006 *Livestock's Long Shadow*[41] report. This estimated that livestock contribute 7.1 Gt CO2-eq or 18% of global anthropogenic greenhouse gas emissions, and to many other environmental problems. The subsequent 2013 revised version[42] came to a similar estimate of the *absolute* impact but since other sources of emissions (industry, transport and so forth) had increased over that period, the overall anthropogenic emissions total – against which livestock emissions were compared – was also higher. This means that the proportional overall contribution of livestock fell to a slightly lower 14.5%.

These reports, and burgeoning associated academic literature, have catalysed an explosion of societal activity, and have added weight to the longer standing arguments of animal rights and welfare organisations such as PETA, Humane Society International and Compassion in World Farming, who have always had concerns about animal production. While animal rights organisations condemn all livestock rearing of all kinds, welfarists, who do accept some forms of animal production, tend to focus their concerns on so-called intensive or 'industrialised' systems. For them, it is an inconvenient truth that most life cycle assessments find more extensive systems – traditionally viewed as better for welfare –to have a higher carbon footprint than industrialised ones.[43,44] These groups are therefore particularly interested in the possibility that more extensive grazing systems, inherently better for animal welfare, could also ultimately be more environmentally benign than intensive ones, once the sequestration effects are accounted for.

Most NGOs base their advocacy on the FAO reports and on academic studies. A few others have chosen to adopt more extreme positions, most strikingly the US based Worldwatch Institute, which in 2011 published a report claiming that livestock generate as much as 51% of global GHGs.[45] The science behind these claims has been comprehensively refuted – among other things because it counts livestock respiration as a source of CO_2[46] – but the figure holds traction in some quarters and the report inspired the very popular 'Cowspiracy' film, produced by Leonardo DiCaprio.[47]

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41 FAO (2006). *Livestock's long shadow: environmental issues and options*. Food and Agriculture Organisation of the United Nations, Rome, Italy.

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

43 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, pp. 760-770.

44 Ripple, W.J., Smith, P., Haberl, H., Montzka, S.A., McAlpine, C. and Boucher, D.H. (2014). Ruminants, climate change and climate policy. *Nature Climate Change,* 4, pp. 2-5. Doi:10.1038/nclimate2081.

45 Goodland, R. and Anhang, J. (2011). Livestock and Climate Change: What if the key actors in climate change are… cows, pigs, and chickens? Worldwatch Institute, Washington DC, USA.

46 Herrero, M., Gerber, P., Vellinga, T., Garnett, T., Leip, A., Opio, C., Westhoek, H.J., Thornton, P.K., Olesen, J., Hutchings, N., Montgomery, H., Soussana, J.-F., Steinfeld, H. and McAllister, T.A. (2011). Livestock and greenhouse gas emissions: The importance of getting the numbers right, *Animal Feed Science and Technology*, Volumes 166–167, 23 June 2011, pp. 779-782, ISSN 0377-8401, 10.1016/j.anifeedsci.2011.04.083.

47 Cowspiracy [online] (2015). http://www.cowspiracy.com/ (accessed 11.7.17).

Countering these civil society voices are the mainstream livestock farming sector which argues that intensification has delivered massive reductions in GHG emissions per unit of meat or milk produced, and that additives such as growth hormones, if rolled out, could generate further savings.[48]

Other stakeholders find common ground with the anti-livestock movement in condemning intensive animal agriculture, but instead of arguing for dietary change they advocate a shift to 'alternative' systems of livestock production and associated meat consumption.[49] Perhaps the most charismatic and most extreme proponent of the sequestration claim is Allan Savory, whose TED talk entitled 'How to fight desertification and reverse climate change' has been a rallying cry for grassfed advocates worldwide. For these stakeholders, grazing livestock offer planetary salvation, not damnation. The UK's Sustainable Food Trust (SFT) has also been very active in promoting the holistic grazing approach and goes so far as to argue that we should be eating more, rather than less, ruminant meat.[50] The SFT hails Joel Salatin's 'Polyface Farm' in the US as an exemplar of integrative sustainable livestock farming: holistic (also called adaptive) grazing lies at the core of the farm's operational model. The pro-grassfed movement is spreading across the world and includes organisations such as Carbon Farmers of Australia, the Soil Carbon Coalition, Carbon Farmers of America, the Rodale Institute[51] and the UK based Pasture Fed Livestock Association. It has spawned its own widely viewed films such as Soil Carbon Cowboys and numerous YouTube videos.

While these are extreme voices and stances, there is genuine scientific uncertainty around the role of grazing systems in affecting soil carbon, and political uncertainty about which GHG sources should be prioritised in mitigation efforts. As such, lurking inside some of the more outrageous claims and counterclaims, are real and important research questions that need to be investigated.

At regional and national levels, the contribution farm animals make to overall emissions depends on what production systems dominate (emission intensities measured in tonne CO_2-eq per tonne edible ruminant protein vary widely by system and agro-ecological context),[52] the size of the livestock sector and of course on how high emissions are from other sectors such as industry or transport. Absolute emissions may be large even where relative emissions are low because emissions from the industrial sector, say, are so significant.

Moving down to the level of consumption and diet, numerous studies find that animal products – particularly those of ruminant origin – generally have high emissions intensities relative to other foods. Meat heavy eating patterns tend to be more

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48 Capper, J.L., Castañeda-Gutiérrez, E., Cady, R.A., Bauman, D.E. (2008). The environmental impact of recombinant bovine somatotropin (rbST) use in dairy production. *Proc Natl Acad Sci*, 15(28), pp. 9668–9673

49 Soil Association (2016). Organic cows: better for the planet [online]. https://www.soilassociation.org/news/2016/march/15/organic-beef-and-dairy-good-for-us-the-environment/ (accessed 11.7.17).

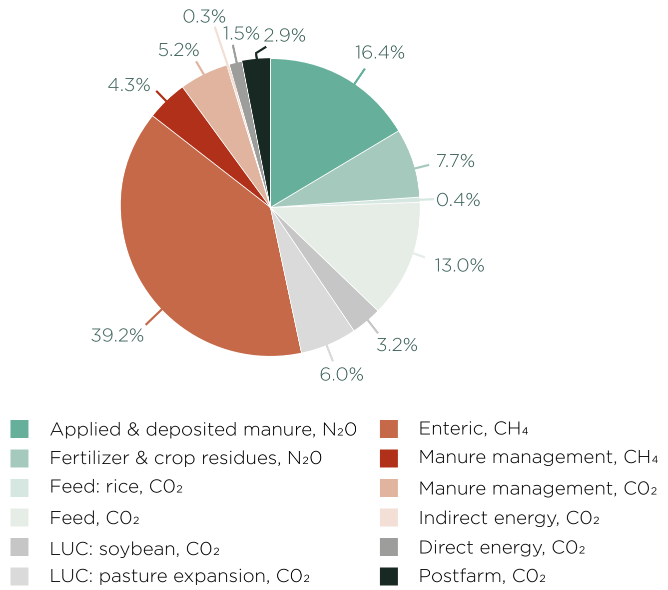
50 Sustainable Food Trust (2014). What meat to eat? A debate [online]. http://sustainablefoodtrust.org/articles/the-great-debate-on-eating-less-and-better-meat/ (accessed 11.7.17).

51 Rodale Institute (2014). *Regenerative Organic Agriculture and Climate Change: A Down-to-Earth Solution to Global Warming*, Rodale Institute, PA, USA.

52 Herrero, M., Havlík, P., Valin, H., Notenbaert, A., Rufino, M.C., Thornton, P.K., Blümmel, M., Weiss, F., Grace, Obersteiner, M. (2013). Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. *Proc Natl Acad Sci* USA, 110(52), pp. 20888-20893.

emissions intensive than those where animal products feature little or not at all.[53] There are of course exceptions, and challenges to these conclusions which are discussed further in Chapter 5.

Figure 2: Global greenhouse gas emissions from livestock production by emissions source and gas type. From Gerber *et al.* (2013).[54]



Livestock contribute 14.5% of human-made GHG emissions

Of this 14.5%

- Enteric fermentation from ruminant animals contributes nearly 40% of livestock GHGs
- Emissions related to manure contribute around 25%
- Production of animal feed contributes around 13%
- Land-use change for livestock contributes nearly 10%
- Post-farm emissions (processing & transport from farm to retail) contributes only 2.9%

Cattle dominate livestock related emissions, contributing around 65% of the total,[55] buffaloes and small ruminants add a further 9% and 7% respectively, so in all ruminants account for over 80% of total livestock related climate impacts, most significantly via enteric methane (Figure 3) – which are highest, per unit of milk or meat, in grazing systems. Other studies give broadly comparable estimates.[56] This 80% share of GHG emissions is worth setting against the 50% that ruminants contribute to overall terrestrial animal product protein supply (Figure 3). Grazing systems specifically emit an estimated 1.32 Gt CO_2-eq[57] (a figure that includes land use change-related impacts), which is about 20% of all emissions from livestock.[58]

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[53] Garnett, T. (2016). Plating up solutions: Can eating patterns be both healthier and more sustainable? *Science*. 353(6305), pp. 1202-1204.

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

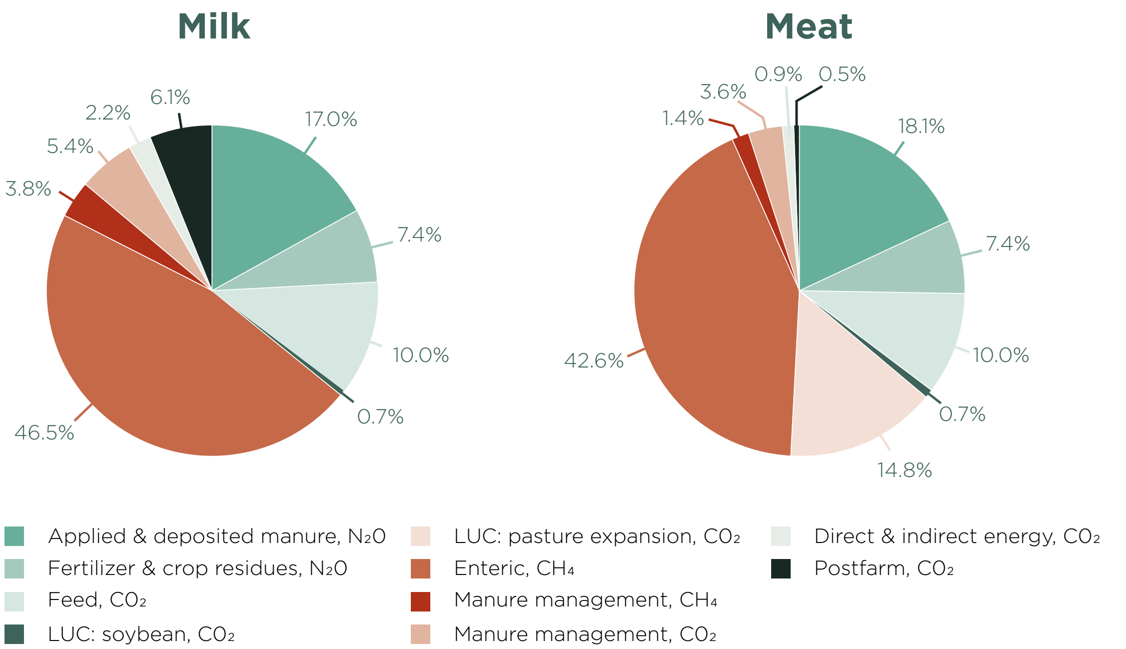
[55] *Ibid.*

[56] Herrero, M., Henderson, B., Havel, P., Thornton, P.K., Smith, P., Wirsenius, S., Hristov., Gerber, P., Gill, M., Butterbach-Ball, K., Vain, H., Garnett, T. and Stehfest, E. (2016). Greenhouse gas mitigation potentials in the livestock sector. *Nature Climate Change*, 6, pp. 452-461.

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

[58] *Ibid.*

Figure 3: Breakdown of global greenhouse gas emissions attributable to cattle milk and meat by emissions source and gas type. From Gerber *et al.* (2013).[59]



Inevitably, these estimates are inherently uncertain for many reasons, not least being the difficulty of putting accurate numbers on biological and biophysical systems that vary and fluctuate at multiple scales, from the animal's individual metabolism through to the landscape and climate, vary widely by animal and manure management regimes, and problems of data absences and inadequacies.[60] Caveats notwithstanding, the evidence clearly shows that livestock are major emitters of greenhouse gases.

None of these estimates, however, take account of any carbon sequestration that grazing ruminants might help achieve, through the effects of their actions on the uptake of carbon from soils. It is argued that these figures not only exaggerate the contribution that the livestock sector makes to global GHG emissions, but – most importantly – represent grassfed cattle as villains of the climate piece, when in reality they are its underrated heroes.

This – the sequestration question – forms the subject of the next chapter.

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

60 See Röös & Nylinder (2013) for a review on uncertainties when calculating GHG emissions from livestock. Röös, E. and Nylinder, J. (2013). *Uncertainties and Variations in the Carbon Footprint of Livestock Products*. Swedish University of Agricultural Sciences.

3. Soil carbon sequestration – (how) do grazing livestock contribute?

Key points

- Soils are very significant carbon stores. All soils contain carbon although different soil types differ in how much they contain. Above ground biomass also stores carbon – especially trees.
- As plants grow they draw down carbon from the atmosphere, apportioning some into their roots. Much of this is released back to the atmosphere when plants die and decompose. But, if left undisturbed, some of the carbon in their roots and in plant litter – depending on climate, rainfall, the soil microbial community, management and many other variables – may eventually be incorporated into more stable compounds in the soil, constituting a net removal of carbon from the atmosphere. This is soil carbon sequestration.
- If favourable conditions continue, soils sequester carbon until equilibrium is reached, after which emissions and removals are balanced and no more is sequestered. Further increases in sequestration may be possible if there is a change in how the land is used or managed.
- Sufficient nitrogen needs to be available for plants to grow and therefore for soils to sequester carbon. This can be provided in the form of bacterial nitrogen fixation, such as that associated with the roots of legumes, application of mineral fertilisers or organic amendments containing nitrogen, but higher nitrous oxide emissions may outweigh sequestration gains.
- Since sequestration is time-limited, so too is its role in mitigation efforts. There are additional problems of reversibility (what can be done can be undone) and leakage (organic amendments applied on one area of land may be at the cost of its previous application elsewhere). Legacy effects of past management practices also need recognising to avoid drawing false conclusions about the effects of the current management regime.
- Grazing animals *potentially* aid the process of sequestration as their consumption of herbage stimulates plant growth and leads to the partitioning of and increase in organic matter below ground.
- Factors including soil type and quality, climate and seasonal variability, precipition levels, nutrient availability, composition of soil fauna and microbial communities, and vegetation type will influence whether organic matter is converted into stable below ground carbon which determines if sequestration *actually* occurs.
- In many parts of the world the potential for grazing management to achieve sequestration is limited or absent.
- Heavy grazing is a problem on many grazing lands: by reducing plant growth, it causes carbon losses from the system.

- Evidence as to the sequestration benefits of holistic, adaptive and other variants of rotational grazing is patchy and highly contradictory. Where there are benefits, these are small.
- The highly ambitious claims made about the potential for holistic grazing to mitigate climate change are wrong.
- The sequestration potential from grazing management is between 295–800 Mt CO_2-eq/year: this offsets only 20-60% of annual average emissions from the grazing ruminant sector, and makes a negligible dent on overall livestock emissions.
- Expansion or intensification in the grazing sector as an approach to sequestering more carbon would lead to substantial increases in methane, nitrous oxide and land use change-induced CO_2 emissions.
- Practices that are optimal for achieving soil carbon sequestration may not be so for other environmental goals, such as biodiversity conservation.
- Leaving aside any scope for sequestration it is imperative that we 'keep carbon in the ground': by acting to halt degradation or conversion to croplands to avoid *losing* the huge carbon stocks already stored in grasslands.

Do ruminants in grazing systems help soils sequester carbon and if so, how? Could sequestration be increased, if livestock are managed right? Are there other ways of using the land that would sequester more carbon, and what would the pros and cons of these alternatives be?

This chapter answers these questions in five stages. It begins (Section 3.1) with some basics about what soil carbon is, and how much is stored in soils today; it then moves on (Section 3.2) to provide a general overview of the mechanisms of soil carbon sequestration and then considers (Section 3.3) what approaches, both livestock and non-livestock-related, could achieve sequestration together with their risks and limitations. Section 3.4, the chapter's core, homes in on the livestock question. It looks at how grazing affects changes in the soil carbon balance and what uncertainties, context-specificities and limitations need to be considered, and what claims have been made. It concludes (Section 3.5) with some quantitative estimates of the grazing sector's overall potential.

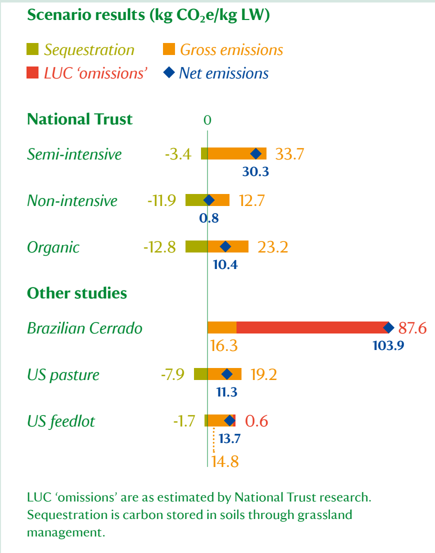
Box 4: Impact of factoring in assumptions about sequestration on the carbon footprint of beef

Most life cycle assessments of ruminant products assume that the soil carbon balance is in equilibrium when there is no change in land use or management practice in line with IPCC guidelines. Greenhouse gas emission from pasture-based systems are generally greater per kg of meat produced than from more intensive systems in which animals are fed grains and concentrates. This is because in the latter, animals grow and reach slaughter weight faster, or in the case of dairy cows, are more productive. Lifetime emissions are therefore lower overall.[61]

However, some studies factor in assumptions that soils under grazing management continue to accumulate carbon. An example of such a study is one commissioned by the National Trust, a UK charity and major land owner, which assumes that permanent grassland sequesters carbon at a rate of 0.88 t CO_2/yr (whether or not an animal is on it) and that conversion from conventional to organic farming leads to carbon gains of 1.54 t CO_2/yr for grassland and 2 t CO_2/yr in cropland. Since the published data sources for these two assumptions are different, they are not comparable. As Figure 4 shows, using these estimates, the non-intensive British beef farm is carbon neutral. Despite low gross emissions, the Brazilian system has a very high emissions footprint because of historic land use change.

Note that this study assumes quite favourable sequestration rates. Moreover, it does not take into account important caveats, such as the progressively dwindling rates of sequestration over time, leading to eventual equilibrium – issues that are all considered in the main body of this Chapter.

Figure 4: Greenhouse gas emission intensities of different ruminant production systems. From National Trust (2012)[62]



[61] De Vries, Van Middelaar and De Boer (2015). Comparing environmental impacts of beef production systems: a review of LCAs. *Livestock Science,* 178, pp. 279–s288.

[62] National Trust (2012). *What's your beef?* National Trust, Swindon, UK.

3.1 What is soil carbon? How much carbon is stored in soils today?

Carbon in the soil can occur in two forms: as inorganic carbon – for example as carbon containing minerals such as carbonates; and as organic carbon – the carbon found in organic matter derived from living or dead organisms. Inorganic carbon pools are found only in soils where carbon-containing minerals occur, and inorganic carbon stocks can be changed gradually by some land management practices such as fertilisation, which can affect the acidity of the soil; but it is the soil organic carbon (SOC) that changes most rapidly in response to land use and management change and this is what people are referring to when they talk about soil carbon and mitigation.

Soil organic matter (SOM) comprises a range of organic molecules ranging from small, easily degraded ones such as sugars exuded by plant roots, through to large, complex organic compounds which resist decomposition and can remain in the soils for decades or centuries. Like all living or once living material, SOM is made up of many elements including carbon, nitrogen, oxygen, hydrogen, sulphur and phosphorus. The carbon component comprises about 58% of the dry matter of SOM and so estimates of SOM need to be multiplied by 0.58 to obtain the SOC content.

The total stock of SOC on earth (to a depth of 1 metre) is 1500 GtC (5500 Gt CO_2 – see Box 5 on units),[63] which is twice the amount of carbon found in terrestrial vegetation, and three times the amount found in the atmosphere, so it is a very significant global carbon pool.

Box 5: A note on units

In this report, the emissions from the non-CO_2 greenhouse gases (methane and nitrous oxide) are expressed as CO_2 equivalents (CO_2-eq) by taking their Global Warming Potentials (GWPs) over a 100 year time horizon and expressing in terms of equivalence to CO_2. According to the IPCC's Fifth Assessment Report (AR5),[64] the GWP of biogenic methane is 28, of fossil methane 30, and of nitrous oxide 265. Thus, 1 kg of biogenic CH_4 is 28 kg CO_2-eq, and 1 kg of N_2O is 265 kg CO_2-eq. These values do not include climate carbon feedbacks, feedbacks which measure the indirect effects of changes in carbon storage resulting from changes in climate. GWPs including climate carbon feedbacks are somewhat higher (34 for biogenic methane, 36 for fossil methane and 298 for nitrous oxide). Most studies cited in this report use GWPs from the IPCC's Fourth Assessment Report (AR4) which gives 25 for biogenic and fossil methane and 298 for nitrous oxide. While most studies use GWP for summing GHGs, Chapter 4 discusses an alternative to this approach.

63 Batjes, N.H. (1996). Total carbon and nitrogen in the soils of the world. *European Journal of Soil Science*, 47, pp. 151-163.

64 Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang. (2013). *Anthropogenic and Natural Radiative Forcing*. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Studies that focus on soil carbon usually – although not always – refer to carbon (C). This often becomes a source of confusion when numbers are compared because the weights of carbon and carbon dioxide are different. A tonne of carbon dioxide contains much less actual carbon – oxygen makes up most of the weight. The molecular weight of carbon is 12 (expressed as 12 g/mol). The molecular weight of oxygen is 16 (16 g/mol) and there are two atoms of oxygen (each with a molecular weight of 16) for every atom of carbon. As such, one tonne of carbon dioxide only contains 12/44 = 0.27 tonnes of carbon.

Strictly speaking, the carbon sequestration potential should only be referred to in terms of carbon since soils do not hold CO_2. However, to enable ready comparisons with atmospheric emissions of CO_2 or of other greenhouse gases (as CO_2 -eq) this report also shows the carbon sequestration potential expressed in terms of CO_2 – that is the amount of carbon in soils that, if were released into the atmosphere would combine with oxygen to form CO_2. This is done by multiplying the mass of carbon (see Box 6 for how this is obtained) by 44/12 = 3.667. So 1 tonne of carbon is equivalent to 3.667 tonnes of carbon dioxide.

When claims are made about the sequestration potential of different management types, the unit needs to be noted, to avoid the risk of making inaccurate comparisons or claims.

It is important at this point to distinguish between *storage* and *sequestration.* The former is the quantity of carbon trapped or locked into the soil (the stock); the latter refers to the net transfer of carbon from the atmosphere to soil or biomass (the income). Carbon can of course also be stored in above ground vegetation.

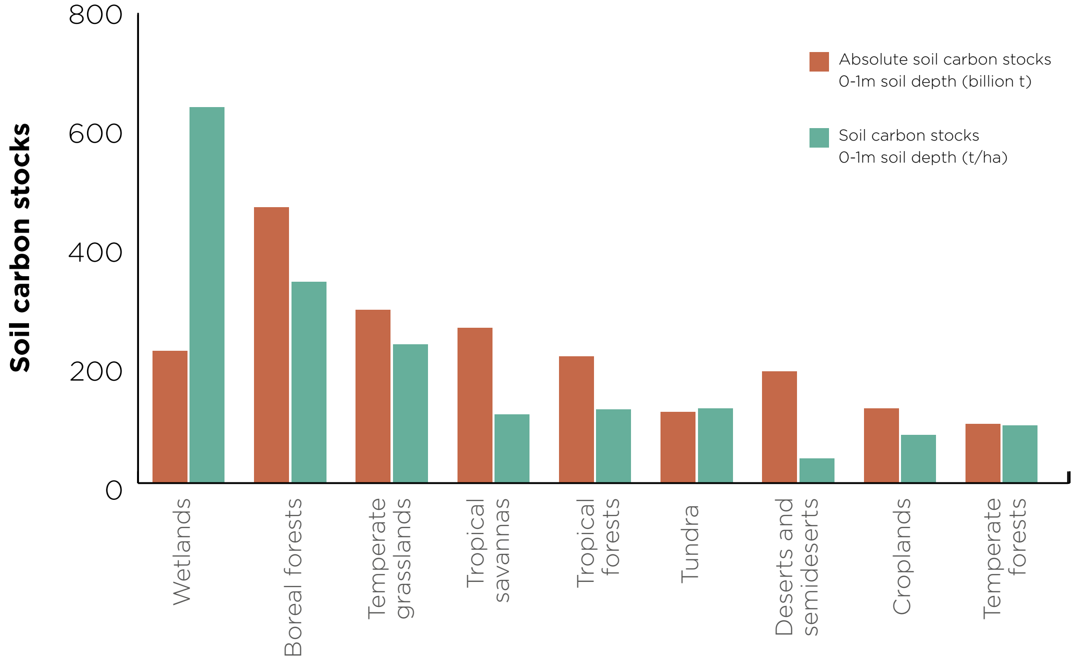
Soils and mature forests can have important stores of carbon within their biomass without sequestering much. Young forests and soils that are managed in a particular way so as to accumulate organic matter sequester carbon. The sequestration rate diminishes to zero over a period of decades as soils reach a new state of carbon equilibrium, and gains can be lost if soils are ploughed up or inputs of carbon cease (see Section 3.3).

Peatlands store the most soil carbon per hectare by a long way, followed by boreal forests and then temperate and tropical grasslands. But because of their larger land area in absolute terms, boreal forests are the largest soil carbon stores, followed by temperate and tropical savannas – the latter hold about a third of total global soil carbon stocks (Figure 5).[65,66] Of course, there is also considerable carbon in above ground vegetation.

[65] IPCC (2000). *Land use, land use change and forestry*. Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, R.H., Verardo, D.J. and Dokken, D.J. (Eds.) Cambridge University Press, UK.

[66] White, R., Murray, S., and Rohweder, M. (2000). *Pilot Analysis of Global Ecosystems: Grassland Ecosystems*, World Resources Institute, Washington D.C.

Figure 5: Absolute stocks and stocks per hectare per biome. Data from IPCC (2000)[67]



Box 6: How are carbon stocks and carbon sequestration rates in soils measured?

To assess the effect of a management practice on soil carbon, one needs to measure the soil's organic carbon composition. There are several ways of doing this, the most reliable being to use an augur – a drill that typically takes a sample of soil down to 20-100 cm in depth.

The soil then has to be analysed. The most accurate method is to use a dedicated carbon and nitrogen analyser. These are commercially available and use a dry combustion method to estimate the concentration of organic carbon in the soil sample. These instruments heat a small sample (a fraction of a gram) of dry pulverised soil to around 900°C and measure the CO_2 produced – they usually measure nitrogen as well.[68] The results are expressed as the percentage of carbon in the sample. The carbon stock is then calculated by multiplying the percentage of carbon (e.g. 2%) by the depth of the measurement in cm (e.g. 30 cm) by the soil's bulk density in g/m^3. By repeating soil sampling over a range of years the change in carbon stocks (loss or gain) can be estimated. Note that when measuring changes in soil carbon over time it is essential to take account of changes in the soil's density. This can be managed by basing calculations on the same mass of soil rather than to a standard soil depth.

Typically, the top 30 cm of soils contains the largest concentration of carbon. Nevertheless, while greater depths contain lower concentrations, they may store a great deal in absolute terms – one study of UK soils finds that around 60% of all its stored carbon is in the zone below 30 cm. These lower depths have been

[67] IPCC (2000). *Land use, land use change and forestry*. Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, R.H., Verardo, D.J. and Dokken, D.J. (Eds.) Cambridge University Press, UK.

[68] Donovan, P. (2013). Measured soil carbon change [online]. http://soilcarboncoalition.org/changemap.htm.

far less researched since measurements are harder to take. Proponents of organic farming are particularly keen to highlight the knowledge gaps here as they claim that organic management does a better job of pushing carbon down into these lower depths than conventional farming. This is an area where more routine measurement and experimentation is certainly needed, and there have recently been encouraging advances in developing the necessary tools.[69,70]

Flux measurements are another way of estimating changes in soils carbon stocks. This method measures gaseous fluxes from the soil-vegetation surface but does not measure carbon losses in other forms, such as dissolved carbon. To estimate the total organic carbon change, one has to estimate all the other sources and sinks of carbon that may not be in gaseous form so as to derive, by subtraction, the change in soil organic carbon. This reliance on estimates makes flux measurement approaches less reliable than the augur and combustion method.

Perhaps even more problematic are the current practical and economic limits on our ability to measure soil carbon at a large scale. First, to get an accurate picture of current stocks and future changes, it is necessary to sample widely to ensure that measurements are representative of the entire land area, as even patches very close to one another can vary considerably in their carbon content. Control areas may also need to be sampled if the aim is to assess the effects of a change in management. Taking samples is time consuming and expensive.

Then, there are the temporal dynamics to consider. The soil organic carbon content changes slowly and only marginally from year to year, so change needs to be measured over a long time-frame. Typically, the initial rate of sequestration may begin quite high and then progressively diminish until equilibrium is reached.

Any change in carbon is, moreover, being measured against huge background stocks. The 'noise' from the uncertainties in actually measuring the baseline stock can make it hard to measure the relatively small changes taking place.

All these uncertainties and the need for a longer-term view are important to recognise when dramatic claims are made about increases in SOC achieved after just a few years. Usually it takes about a decade to gain a sense of the direction of change – and as noted it is essential to have a reasonable number of samples and adequate statistical power to adjust for the 'noise'.[71]

Finally, as interest in soil carbon as a potential mitigation measure grows,[72] motivated farmers are increasingly keen to measure changes in the soil carbon on their farms. High costs and the scarcity of accurate measurement tools for the non-specialist make this difficult. Clear information, accurate, affordable tools and robust verification procedures are very much needed so that farmers, researchers and policy makers can learn from the natural experiments of innovative farmers, and to avoid the risk that inaccurate or over optimistic claims gain currency.

69 Zimmermann, M., Leifeld, J., Schmidt, M.W.I., Smith, P. and Fuhrer, J. (2007). Measured soil organic matter fractions can be related to pools in the RothC model. *European Journal of Soil Science*, 58, pp. 658-667. doi: 10.1111/j.1365-2389.2006.00855.x.

70 Ostle, N.J., Smith, P., Fisher, R, Woodward, F.I., Fisher, J.B, Smith, J.U., Galbraith, D., Levy, P., Meir, P, McNamara, N.P. and Bardgett, R.D. (2009). Integrating plant–soil interactions into global carbon cycle models. *Journal of Ecology*, 97, pp. 851-863. doi: 10.1111/j.1365-2745.2009.01547.x.

71 Smith, P. (2004). How long before a change in soil organic carbon can be detected? *Global Change Biology* 10, pp. 1878-1883.

72 4 pour 1000 (2017). Understand the "4 per 1000" initiative [online]. http://4p1000.org/understand (accessed 11.7.17).

When natural systems are converted to agricultural use, soil carbon stocks usually decline, often by as much as 60% ifthe conversion is to cropland.[73] Within agricultural lands, since grasslands contain more carbon than croplands, soil carbon decreases when grasslands are converted to cropland, and vice versa.[74]

3.2 How does sequestration work?

Sequestration is the process of removing carbon from the atmosphere, where it is present in the form of CO_2, and drawing it down into the terrestrial pool, via the plants growing on the land.

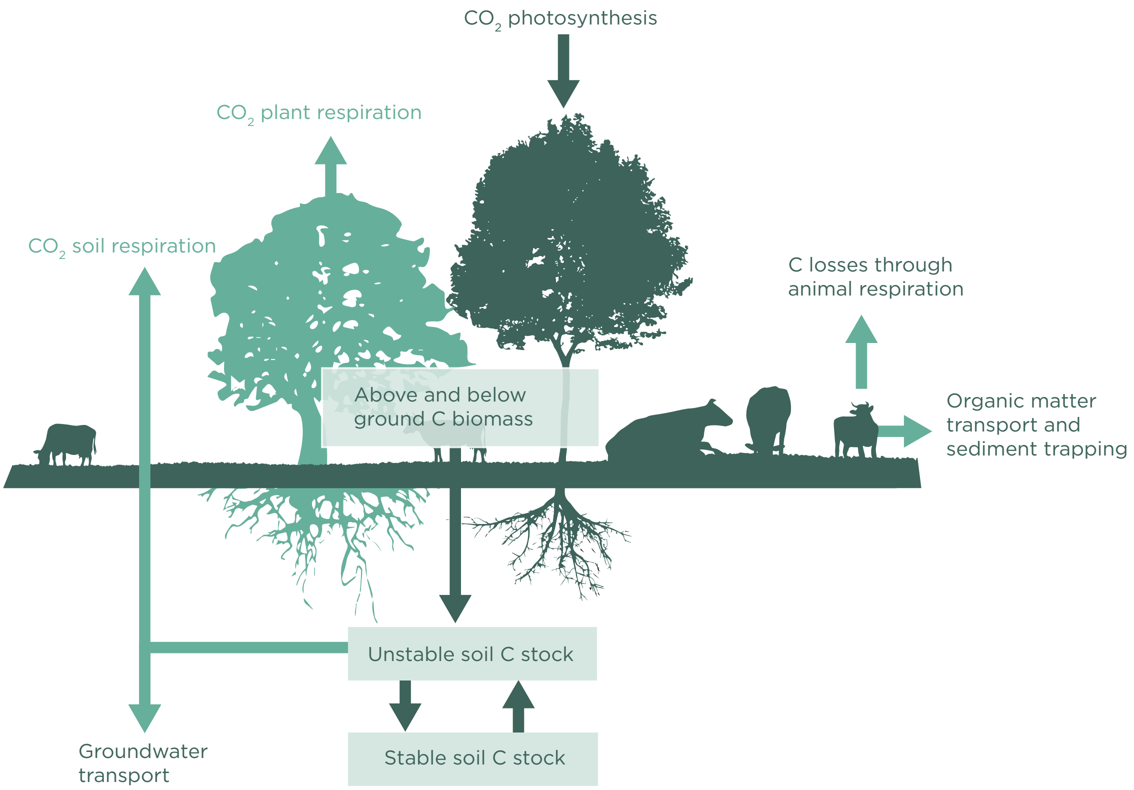
Sequestration works like this: plants take in carbon dioxide through their stomata, the microscopic openings, in their leaves. Through photosynthesis, some of the CO_2 is converted into a food source, glucose, and then into other compounds to build the plant's biomass (accompanied by a production of oxygen), and then water and some CO_2 is released back into the atmosphere through respiration. Many microbial organisms also utilise CO_2 in a similar way.

As the plant grows, so does the carbon it contains. Some of this carbon will be in its above ground biomass (stem, leaves, flowers, seeds), and some in its root structure. When plants and other forms of biomass, such as worms, die and decay most of this carbon is emitted back to the atmosphere as CO_2 over a period of weeks or months, and the net effect on atmospheric CO_2 concentrations is therefore zero. But some may be converted into more stable carbon compounds that can stay in the soil for decades or even hundreds of years. This might occur if biomass is buried or otherwise drawn down deep into soils where it is not disturbed: if it is already below ground (as plant roots are) and left there in peace, or if the carbon in the above ground vegetation is processed into forms that are less prone to decay, such as biochar. There is no inevitability about this conversion though – the organic matter in a soil may increase, but if the carbon it contains remains in a very labile form, it will be re-released within a matter of weeks or months. It does not necessarily become converted into a more stable form and thus in the long term the soil carbon content may not in fact increase (although soils rich in organic matter nonetheless offer advantages for soil texture, water retention and ultimately for crop productivity). The presence of favourable soil and climatic conditions, as well as management regimes, is critical to the formation of soil carbon and the maintenance of its stability. Figure 6 provides a simple illustration of the sequestration process.

[73] Guo, L.B. and Gifford, R.M. (2002). Soil carbon stocks and land use change: a meta-analysis. *Global Change Biology*, 8, pp. 345-360.

[74] Richards, M., Pogson, M., Dondini, M., Jones, E.O., Hastings, A., Henner, D. Tallis, M., Casella, E., Matthews, R., Henshall, P. Milner, S., Taylor, G., McNamara, N., Smith, J.U. and Smith, P. (2017). High-resolution spatial modelling of greenhouse gas emissions from land-use change to energy crops in the United Kingdom. *Global Change Biology Bioenergy*, 9, pp. 627-644. doi: 10.1111/gcbb.12360.

Figure 6: Key carbon cycling dynamics in terrestrial ecosystems



Note: This Figure provides a simplified representation of some key carbon cycling dynamics in terrestrial ecosystems . For further details on land management impacts on soil carbon stocks and carbon cycling dynamics in grazing systems, see Sections 3.3 and 3.4.

Terrestrial – including agricultural – ecosystems can be a source of carbon when the pace of respiration and organic matter oxidation exceeds the pace of CO_2 fixation through photosynthesis. This might happen if land is overgrazed, trees felled, biomass burned, or carbon-rich peat soils drained or ploughed up. If the reverse happens, they can function as a sink, and there is a net transfer of carbon from the atmosphere to the soil, or to the growing biomass.

3.3 What land management approaches hold potential to sequester carbon? And what are their risks and limitations?

Many land management options have potential to achieve carbon sequestration in soils as well as in above ground biomass.[75] Afforestation and reforestation are perhaps the

[75] Smith, P.M., Bustamante, H., Ahammad, H., Clark, H., Dong, E.A., Elsiddig, H., Haberl, R., Harper, J., House, M., Jafari, O., Masera, C., Mbow, N.H., Ravindranath, C.W., Rice, C., Robledo Abad, A., Romanovskaya, F., Sperling, and F. Tubiello (2014). *Agriculture, Forestry and Other Land Use (AFOLU)*. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

most obvious and most traditional example – carbon will be sequestered in above-, as well as below-, ground biomass.

In croplands, options include adding carbon-rich matter to soils (such as manure, compost, or crop residues); and management options that reduce carbon losses, such as conservation agriculture, reduced tillage or growing perennials (such as ley, fruit and nut trees or future perennial versions of current annual crops) to reduce soil disturbance. Additional options include planting legumes to stimulate plant productivity and thereby increase carbon inputs to soils; and using catch crops, crop rotations and inter-cropping to maintain vegetation cover and ensure that carbon inputs continue year-round. As with all land management options, these options come with caveats and trade-offs which may variously include increased N_2O emissions, problems with weed control or lower productivity per area over time.

In grasslands, sequestration measures may include planting deep rooted grasses; adding legumes; adding carbon-rich matter such as manure to soils, stimulating forage productivity (including through better water and nutrient management); fire management – and changing the management of grazing (timing and intensity) – discussed in some detail in Section 3.4.

While not all sequestration approaches involve animals in grazing systems, many *indirectly* affect assessments about the merits of using ruminants to sequester carbon, since land is limited. There may be an opportunity cost; using land or organic matter for one purpose or on one area precludes its use for another, and any decision made could have subsequent effects on land use and soil carbon somewhere else.

For example, if crop residues are incorporated into soils, then the animals that were previously eating those residues will either go unfed, or have to consume bought-in feeds – which may cause land use change somewhere else.[76] Alternatively, an area of grazing land could be used to plant trees: this will sequester carbon, but the land can now no longer be grazed (although sometimes silvo-pasture may be an option[77,78]). The carbon gains from afforestation need to be compared with those possible through better grazing management, and the effects will vary by context.[79] And since most tree planting does not provide food, the knock-on effects need considering: what are the consequences for land of obtaining the equivalent amount of food by grazing animals somewhere else, or shifting to landless livestock systems, or growing crops? Section 5.4 discusses some hypothetical scenarios.

[76] Giller, K.E, E. Witter, M. Corbeels and P. Tittonell (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research,* 114(1), pp. 23-34.

[77] Beckert, M.R., Smith, P., Lilly, A. and Chapman, S.J. (2016). Soil and tree biomass carbon sequestration potential of silvopastoral and woodland-pasture systems in North East Scotland. *Agroforestry Systems* 90(3), pp. 371-383. 371. doi:10.1007/s10457-015-9860-4.

[78] Tonucci, R.G., Nair, P.K., Nair, V.D., Garcia, R., Bernardino, F.S. (2011). Soil carbon storage in silvopasture and related land-use systems in the Brazilian cerrado. *J Environ Qual*., 40(3), pp. 833-41. doi: 10.2134/jeq2010.0162.

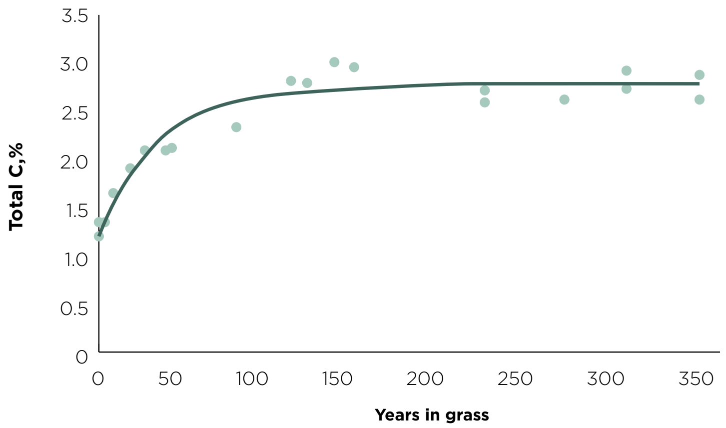
[79] Guo, L.B. and Gifford, R.M. (2002). Soil carbon stocks and land use change: a meta analysis. *Global Change Biology*, 8, pp. 345-360.

There are, moreover, considerable problems with using soil carbon sequestration as a climate mitigation approach.[80,81]

The first is that carbon sinks are reversible – what can be done, can be undone. Soil carbon stocks can increase through good soil management, but also be lost through bad management. This is a very real danger given changes in farm ownership – and thus the quality of management expertise or its focus – and the many variables that influence whether a particular management practice continues. Climatic fluctuations, such as a drought for example, can also reverse any carbon gains. These risks underline the point that it is even more important to preserve existing stocks of carbon in soils and forests than it is to try to sequester more carbon.

Second, while soil carbon stocks increase quite rapidly after an improved management regime is implemented, the rate of increase progressively declines (see Figure 7). As soils approach a new equilibrium (where carbon flow in equals carbon flow out), perhaps over 30-70 years, the net removal of CO_2 from the atmosphere dwindles to zero. Generally the more degraded the soils, the more they can sequester before this saturation point is reached – soils in good condition may not be able to sequester much if any more carbon. More importantly still, the stock also needs to be maintained since any change in management which undermines the improved regime – that is, that decreases the higher carbon input – could reverse the sink, and partially or completely undo the mitigation effect.

Figure 7: The changing rate of soil carbon sequestration over time as equilibrium is reached. From Smith *et al.* (2014)[82]



Note: This graph show the increase in organic carbon (% C to 23 cm depth), calculated from total N values presented in Johnson et al. *(2009),*[83] *assuming a C:N ratio of 10:1. Total N values were from a number of silky clay loam soils sown to grass from cropland at various times and for various periods at Rothamsted, UK.*

[80] Smith, P. (2005). An overview of the permanence of soil organic carbon stocks: influence of direct human-induced, indirect and natural effects. *European Journal of Soil Science*, 56, pp. 673-680.

[81] Smith, P. (2012). Soils and climate change. *Current Opinion in Environmental Sustainability,* 4, pp. 539-544. doi: 10.1016/j.cosust.2012.06.005.

[82] Smith, P. (2014). Do grasslands act as a perpetual sink for carbon?. *Global Change Biology*, 20(9), pp. 2708-2711.

[83] Johnson, A.E., Poulton, P.R., Coleman, K. (2009). Soil organic matter: its importance in sustainable agriculture and carbon dioxide fluxes. *Advances in Agronomy*, 101,pp. 1-57.

That said, soils may be in equilibrium but not fully saturated – the uptake of carbon is matched by losses, but a change in management regime (or natural conditions) could potentially increase the soil's saturation capacity up until a new saturation point is reached. Soils under a well-managed, tillage-based regime may be in equilibrium, but if there is a switch in management to conservation cropping, which does not involve tillage, then the potential saturation point may increase, as will a switch to grassland. Of course there may be practical disadvantages in increasing the saturation capacity (for example a loss of food output), and there are also biophysical limits – soils cannot accumulate carbon in perpetuity.

Third, there are carbon-nitrogen interactions to consider (Section 4.2 discusses this in more detail). Nitrogen is essential for plant growth but in many parts of the world it is insufficiently available, meaning that the sequestration potential cannot be fulfilled. Where nitrogen inputs can be and are applied, in the form of minerals, or planted legumes, soil carbon may increase, but the release of N_2O may also be exacerbated. As discussed further in Section 3.5 and Chapter 4, using grazing livestock to promote sequestration will also cause methane and nitrous oxide to be emitted. The net GHG balance will depend upon whether the sequestration gains outweigh these other emissions.

Fourth, there are risks of displacement or leakage. One might, for example, enhance soil carbon stocks in one area by applying large inputs of organic matter, but if that matter would otherwise and in any case have been applied somewhere else, the other area stands to lose carbon.[84] Overall, the impact across the two areas is neutral – there is no net carbon removal. Displacement or leakage may also occur where land use change to increase carbon stocks in one area leads to land use change that causes carbon release in another area. Converting a cropping area to pasture would promote carbon sequestration on that land but might also trigger the compensatory conversion of forests or pasture elsewhere to cropland, with corresponding carbon losses.

Finally, misleading conclusions are sometimes drawn about the sequestration effects of a particular land management regime. For example, sequestration in a grassland may be credited to a particular grazing regime when this is in fact the legacy effect of the land's much earlier conversion from arable to grassland:[85] in such a case, a large part of the carbon would likely be accruing even under sub-optimal grazing regimes – and even if there were no animals grazing on the grass.

In all, while sequestration may offer important potential for drawing down atmospheric carbon, it is perhaps even more important to *avoid* any change in land use, such as forest clearance or the conversion of grasslands to arable land, which causes carbon release – to stop things from getting worse. Any carbon *losses* have a permanent effect on carbon concentrations in the atmosphere, whereas activities that *sequester* carbon have diminishing rates of return and come hedged with problems of leakage and reversibility.

[84] Powlson, D.S., Whitmore, A.P. and Goulding, K.W.T. (2011). Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and the false. *European Journal of Soil Science,* 62(1), pp. 42-55.

[85] Smith, P. (2014). Do grasslands act as a perpetual sink for carbon?. *Global Change Biology*, 20(9), pp. 2708-2711.

3.4 Focus on ruminant animals and grazing systems: what grazing management approaches could potentially sequester carbon?

Can good grazing management per se achieve soil carbon sequestration? And if so, how?

Many claims, some very ambitious, have been made about the ability of good grazing management to remove carbon from the atmosphere and sequester it in soils. To understand these claims it is necessary to know the mechanisms through which the management of animals and the land they are grazing upon might actually affect the accumulation or loss of carbon in soils. This section therefore starts with a very simple overview of this process.

It then goes on to examine two main ways in which farmers can potentially promote carbon sequestration on their grazing lands. The first is to modify the grazing land vegetation in ways that stimulate the process of carbon uptake by the plants. The second is to change aspects of *how* their animals are grazed – here we look at two options that receive particular attention: adjustments to the stocking rate, and changes to the timing of grazing. The final sub-section discusses the many agro-ecological variables that influence the effects of any one grazing management practice.

3.4.1 What are the mechanisms by which sequestration might be achieved in grazing systems?

Grazing animals affect soil carbon in several ways. First, they eat the vegetation, removing some of its carbon in the process. Much of the carbon they ingest is subsequently lost from the grassland system in the form of CO_2 (through respiration) and CH_4 (through enteric fermentation), and is embedded in the animal carcass or in milk. Some of the carbon though is returned to the soil as dung. If this dung ends up being incorporated into the soil and the carbon contained within it is converted into more stable forms, this can cause soils to gain carbon. But this is only one of dung carbon's pathways. Some of the dung carbon will be lost as CO_2 and methane, and the fact that animals move about means that the organic matter may not be evenly distributed, or it may be lost to waterways. A portion of the above ground biomass also dies, uneaten, and either decomposes (generating CO_2 and sometimes methane) or is incorporated into soil – this of course would happen if an animal grazes the land or not.

Another way in which animals affect soil carbon is through their effects on the nitrogen cycle (see Section 4.2 for a more detailed discussion of nitrogen). Of the nitrogen in the plants the animals consume, some will ultimately leave the system in the form of the animal carcass, or milk. The rest is deposited on the ground in the form of dung and urine. Some of the nitrogen in these excreta will leave the system in the form of ammonia or nitrous oxide, or via leaching and run-off. Some, however, will find its way into the soil where it can be taken up by plants and stimulate their growth. This soil nitrogen from dung and urine can also favour soil organic matter decomposition rates, resulting in less stable carbon stocks, with the carbon ultimately lost to the atmosphere as CO_2. The forage that the animals do not eat will also die and decay, releasing its nitrogen back into the soil. All these re-allocations of nitrogen can boost carbon uptake, but they can also increase soil carbon release into the atmosphere.

Grasses can cope with being eaten. If the animals consume the vegetation at a rate that is in balance with the plants' rate of growth, then the plants will continue to draw down more carbon from the atmosphere, in the process reducing nitrogen losses. In fact, grazing can positively *stimulate* plant growth, while as noted the nutrients in the dung can further aid this process. But appropriate grazing does not only stimulate above ground biomass production (leading to the cycling effects described above): the key aspect of interest when it comes to sequestration, is the effects of animal grazing on root growth. High root growth is needed to support high rates of net pasture growth. If plants respond to the grazing stimulus by putting down new roots, then the carbon is already underground and has a better chance of being retained there where it may eventually be converted into more stable forms. Much depends, however, upon climatic and soil conditions (see discussion below) as well as the presence of nutrients such as nitrogen or phosphorus, without which plants cannot grow. Plants also vary by species in how they partition their growth and how deep their roots go.

If grazing is too heavy – that is, if the 'offtake' rate is higher than the capacity of the leaves to photosynthesise and create more leaves and tillers (new plant shoots) – the plants die, which means that their roots also die and, of course, grazing can no longer be supported. Tiller decapitation is also an important factor contributing to plant death at high stocking rates. The sward cannot simply recover itself fast enough, meaning the plants are no longer photosynthesising and taking carbon out of the atmosphere.

There are also the trampling effects to consider. It has been argued that the trampling action of livestock can help manure – and the carbon it contains – become incorporated into the soils, aiding sequestration.[86] But if trampling is too heavy then a host of negative consequences can occur – and there is plenty of practical evidence that attests to this point,[87,88] particularly in wet conditions. Impacts include soil compaction, the soiling of forage meaning that the animals will not eat it, a decline in forage productivity, exposure to wind and water erosion, reduced water infiltration and increased run off, an accelerated release of soil carbon and (for legumes) a reduction in plants' nitrogen fixing capacity.[89,90] One way that farmers deal with the soil compaction is in fact to plough and reseed the pasture – and that ploughing causes soil carbon to be released.

It is important to underline the point that livestock add neither new carbon nor nitrogen into the system. They merely contribute to their accumulation in some compartments (reservoirs) along the cycle: in soils, or in plant and animal biomass. While their role in the recycling process is useful – for example manure and urine

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86 Savory, A. (2015 updated) Response to Request for Information on the "Science" and "Methodology" Underpinning Holistic Management and Holistic Planned Grazing. Available at: http://www.savory.global/wp-content/uploads/2017/02/science-methodology.pdf

87 Dunne, T., Western, D. and Dietrich, W.E. (2011). Effects of cattle trampling on vegetation, infiltration, and erosion in a tropical rangeland. *Journal of Arid Environments,* 75(1), pp. 58–69.

88 Chaichi, M.R., Saravi, M.M. and Malekiane, A. (2005). Effects of Livestock Trampling on Soil Physical Properties and Vegetation Cover (Case Study: Lar Rangeland, Iran) *International Journal Of Agriculture & Biology* 7(6).

89 Drewry, J.J., Cameron, D. and Buchan, G.D. (2008). Pasture yield and soil physical property responses to soil compaction from treading and grazing—a review. *Australian Journal of Soil Research*, 46, pp. 237–256.

90 Briske, D.D., Bestelmeyer, B.T. and Brown, J.R. (2014). Savory's unsubstantiated claims should not be confused with multipaddock grazing. *Rangelands*, 36(1), pp. 39–42.

can make nitrogen more bioavailable to plants while the carbon in manure may be incorporated into soils and also improves its quality – the cycle is a leaky one, with numerous exports, some with undesirable consequences, such as nitrous oxide emissions and nitrate leaching (see Section 4.2). Moreover, not all organic matter that enters the soil is converted into long term, stable soil carbon, since much of it is labile and leaves the system within a period of weeks, months or years as CO_2 when ingested and respired by soil organisms.

While plants naturally take up carbon from the atmosphere, there are several ways (see Section 3.4.2 below) in which, by boosting their growth, this carbon uptake process can be increased, potentially leading to greater sequestration. Of importance to the sequestration process is the extent to which these interventions stimulate root growth as well as above ground vegetation, since carbon in the roots is more likely to remain below ground undisturbed and as such has a better chance of being converted into a stable form of carbon. The link between above ground biomass growth and soil carbon sequestration is, as noted, less direct and rather more precarious.

These then, are the basic routes by which grazing animals potentially aid the sequestration of carbon in soils: by stimulating plant growth (through grazing, and through nutrient cycling) including, importantly, root growth; and by helping carbon be moved from above ground (in the atmosphere, in vegetation) to below ground (buried manure, plant roots) where it can less easily be disturbed.

Essential to note, however, is that while some forms of grazing management will foster this process, others will undermine it and actively deplete soil carbon, as discussed further below (Section 3.4.3). Additionally, a farming regime geared at optimising livestock productivity is not necessarily optimal for sequestration. The maximum number of animals that can be reared without depleting the rate at which plant growth is renewed may actually deplete soil carbon since, as noted, much of the carbon the animals take in is lost via respiration, manure oxidation, enteric methane and in the form of animal products. More animals make more manure but as the manure carbon is just a fraction of the carbon in this cycle, and since this manure carbon does not necessarily become converted into stable forms, the net effect is that the system as a whole may lose soil carbon.

3.4.2 Managing or modifying the pasture to increase soil carbon sequestration

The first approach to promoting sequestration highlighted at the start of this section is to stimulate the rate of plant growth by using fertilisers, or by co-planting nitrogen-fixing legumes, or – in water scarce regions – by irrigating.

How effective are these approaches for climate mitigation? In fact, the evidence is mixed. A study by Henderson *et al.* (2015)[91] considered the global potential of using fertilisers as a way of stimulating sequestration and found that this approach often caused losses either because the plants apportioned their growth into their shoots rather than their roots, or because the nitrogen accelerated carbon decomposition.[†]

[91] Henderson, B.B., Gerber, P.J., Hilinski, T.E., Falcucci, A., Ojima D.S., Salvatore, M. and Conant, R.T. (2015). Greenhouse gas mitigation potential of the world's grazing lands: Modeling soil carbon and nitrogen fluxes of mitigation practices. *Agriculture, Ecosystems and Environment,* 207, pp. 91-100.

Even where sequestration did result, fertiliser-induced increases in nitrous oxide emissions always outweighed the carbon savings.

† Since microbes need nitrogen to utilise carbon sources, to maintain their internal ratio of carbon and nitrogen.

The study also examined what could be achieved by planting legumes. Legumes are often seen as a win-win-win option. They are protein rich, and thus a nutritious feed for the animals, which is the main reason why farmers plant them. By enriching soils with nitrogen they also increase forage production and can substitute for synthetic fertiliser, whose production can be highly energy intensive. That said, legumes can be extremely difficult to manage in association with tropical, as opposed to temperate, pastures, and often additional inputs of phosphorus are needed.[92] In principle, legume planting also promotes sequestration, both by stimulating the grasses' root growth, and through their own root biomass. However, nitrous oxide fluxes can be an unwanted consequence, particularly on some soils and in some climates. Poorly draining water-logged soils, or soils in wet regions can be high emitters, and hot conditions also exacerbate N_2O release (although aridity has a countering effect). The Henderson *et al.* (2015) study[93] sought to examine whether, how far and where the sequestration gains arising from legume sowing were able to compensate for these nitrous oxide emissions. It found that on only 10% of the grazing land did sequestration trump N_2O. If legumes are sown only on these soils then a net 147 Mt CO_2-eq/yr[§] could be sequestered. This is equivalent to about 2 t CO_2-eq/ha/yr, considerably higher than the average 0.21 t CO_2-eq/ha/yr that Henderson estimates to be achievable through the changes in grazing practice discussed below.

§ 203.4 Tg CO_2/yr minus N_2O emissions at 56.9 Tg CO_2-eq/yr.

But on the 90% of soils that are not amenable, N_2O fluxes substantially outweigh the sequestration effect. The study also notes that the increases in grassland productivity that arise from legume sowing also enables higher ruminant numbers to be supported. As a result, methane emissions would also increase and would offset 26% of the global net soil C sequestration potential of legume sowing. An alternative, or additional, approach is to introduce deep rooting grasses such as *Brachiaria* spp. into the pasture, the idea being that the carbon in the dead roots is stored deep underground, making it less prone to release.

Brachiaria spp. and other improved tropical pasture species, have been widely hailed as all-round wonder-grasses: if well-managed, they are highly digestible and nutritious, and it has been claimed that livestock productivity can be doubled, or more. It has also been argued that their increased digestibility leads to reduced methane emissions per unit of production while their deep roots can draw more carbon down into the soil. There are even suggestions that some varieties have been shown also to inhibit N_2O emissions from soils.[94] *Brachiaria* spp. together with other deep rooted grasses such as *Panicum* spp., *Pennisetum* spp., and *Cynodon* spp. are now extensively planted in South America and in parts of Sub-Saharan Africa.

92 Humphreys, L.R. (1991). *Tropical Pasture Utilisation*. Cambridge University Press, Cambridge, England.

93 Henderson, B.B., Gerber, P.J., Hilinski, T.E., Falcucci, A., Ojima D.S., Salvatore, M. and Conant, R.T., (2015). Greenhouse gas mitigation potential of the world's grazing lands: Modeling soil carbon and nitrogen fluxes of mitigation practices. *Agriculture, Ecosystems and Environment* 207, pp. 91-100.

94 CIAT (2016). Four unexplored big wins in agriculture: tackling climate change through landscape restoration [online]. http://blog.ciat.cgiar.org/four-unexplored-big-wins-in-agriculture-tackling-climate-change-through-landscape-restoration/ (accessed 11.7.17).

Some very ambitious claims have also been made as to their sequestration potential[95] but matters have been confused by the fact that many studies (such as Amézquita *et al.* 2008)[96] report carbon *stocks* rather that rates of carbon *sequestration*. Nevertheless, a few recent studies on *Brachiaria decumbens* planted after several years of forest clearance have shown carbon sequestration rates of between 2.90 and 4.51 t CO_2/ha/yr over periods of 20 years or so[97,98] and because of their deep penetrating roots, most of the sequestration has occurred in deeper soil horizons than usually sampled (20–100 cm). That said, it is worth noting that fertilisers are needed to boost the productivity of *Brachiaria* spp. N application rates of 100–150 kg N/ha/yr are not uncommon, generating all the downsides already discussed. Moreover, *Brachiaria* spp. have often been planted as a monoculture, at the expense of natural grassland, at great cost to biodiversity, this will be discussed further in a subsequent report. This has also led to pests and diseases that have sometimes decimated swards.[99]

3.4.3 Changing grazing management to increase sequestration rates

The second method of sequestering carbon on grazing lands – and the one that attracts the most attention by commentators – is to manage the livestock on the land in such a way that plants' uptake of carbon from the atmosphere, and its reallocation below ground, is stimulated. One option is to adjust the *intensity* of grazing – in other words to optimise the stocking rate. And the second is to manage the *timing* of grazing: whether animals are left to grazing continuously, or only at certain times or in certain rotations.

These two options are discussed in turn.

What could changing the intensity of grazing achieve?

There is a wealth of research into the relationship between the livestock stocking rate and changes in soil carbon. Often the stocking rate is referred to as the grazing intensity. The problem is that the word 'intensity' is not always clearly defined.

This word requires an absolute benchmark if it is to mean anything. How many animals on a given area are needed to distinguish a highly intensive system from one that is moderate or light? What about time? The stocking density of a field at a particular

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95 Fisher, M.J., Rao, I.M., Ayarza, M.A., Lascano, C.E., Sanz, J.I., Thomas, R.J., and Vera, R.R. (1994). Carbon storage by introduced deep-rooted grasses in the South American savannas. *Nature*, *371*(6494), pp. 236–238.

96 Amézquita, M.C., Murgueitio, E., Ibrahim, M. and Ramírez, B. (2008). Carbon sequestration in pasture and silvo-pastoral systems under conservation management in four ecosystems of tropical America, in: FAO/CTIC Conservation Agriculture Carbon Offset Consultation. Food and Agriculture Organisation of the United Nations (FAO), Rome, pp. 1–11.

97 Stahl, C., Fontain, S., Picon, K., Mascarenhas-Grise, C., Dezecache, M., Ponchant, L., Freycont, V., Blanc, L., Bonal, D., Blurban, B., Soussana, J-F and Blacfort. V. (2016). Continuous soil carbon storage of old permanent pastures in Amazonia. *Global Change Biology*, doi: 10.1111/gcb.13573.

98 Costa, F., Sales, M., Valentim, J., Bardales, M., Amaral, E., Costa, C. and Catani, V. (2016). Soil carbon sequestration in grass and grass-legume pastures in the western Brazilian Amazon. II International Symposium on Greenhouse Gases in Agriculture, 7th–9th June, 2016, Campo Grande, MS, Brazil.

99 Carneiro, B., Pereira, P.D.H., dos Santos Pina, D., Carnevalli, R.A., Lopes, L.B. and Brasília, D.F. (2014). Intensificação da produção animal em pastagens: Anais do 1o Simpósio de Pecuária Integrada.

point in time may be high but the overall density over a specified period could be either low or high, depending on the farm's size, animal numbers and management regime (this is where the term stocking rate is useful – it refers to the number of animals per hectare over a specified time, usually a year). The word 'intensive' often carries with it many other confounding connotations too (see Box 7).

Box 7: The many meanings of the word intensive

The word intensive often suggests characteristics that go beyond simply the number of animals on the land. For example an intensively managed grazing system may be viewed as having a high range and pharmaceuticals, seeds, mineral fertilisers, irrigation water and feed supplementation; while a low intensity system is characterised as having low stocking densities (few animals per land area) and low input use. The latter may sometimes be referred to as an 'extensive' system – although of course an intensive grazing system may still appear 'extensive' compared with, say, a confined animal feeding operation – and sometimes 'extensive' may simply be used to indicate a large area.

One also has to consider what one is being intensive with – some systems may use few 'hard' inputs, such as fertilisers, seeds and irrigation water, but they are nevertheless intensive in their use of 'soft' ones, such as labour, knowledge, institutional support, or a positive mindset.

Compounding this imprecision is the fact that most studies are local or regional in their focus. This makes sense, since grasslands span such a diverse range of climates, vegetation and soils, the detail of the context is crucial in understanding the relevance of any one particular finding. The intensity of grazing in one locality will be impossible in another. This context-specificity does however make it difficult to form generalisable conclusions as to the right stocking rate.

That said, some points do emerge quite clearly from the many experiments and analyses undertaken. First is that overgrazing – defined here as grazing at stocking densities higher than the land can support – damages soils, leads to soil carbon losses and undermines the provision of other ecosystem goods and services. This is hardly a controversial point, but it needs making: the inflated claims made by some grazing enthusiasts (discussed further below) may cause one to forget that poor grazing on landscapes across the world is a serious problem today; one 2002 estimate puts the area of grazing land that is degraded at 7.7% (263 Mha);[100] a more recent one (2010) suggests that 20-35% of permanent pastures – or 700-1200 Mha (if we assume there are 3500 Mha of permanent pastures)[101] – suffer from livestock-induced degradation.

Where soils are over-grazed, reducing the grazing pressure – including by removing the animals altogether if necessary until the vegetation recovers – can help restore

[100] Conant, R.T. and Paustian, K. (2002). Potential soil carbon sequestration in overgrazed grassland ecosystems. *Global Biogeochem. Cycles,* 16, pp. 1-9. doi:10.1029/2001GB001661.

[101] Conant, R.T. (2010). Challenges and opportunities for carbon sequestration in grassland systems. A technical report on grassland management and climate change mitigation, Integrated Crop Management. Food and Agriculture Organisation of the United Nations, Rome. doi:10.3329/jard.v7i1.4430.

soil carbon and benefit the environment in other ways too. Chang *et al.* (2016)[102] for example attribute the increased carbon sink capacity of European grasslands in recent years to the reductions in livestock numbers, and associated grazing intensity.

Light to moderate intensity grazing is more likely to maintain soil carbon stocks and has greater potential to foster sequestration (on lands where this is possible) than continuously heavy grazing, which is usually damaging and reduces soil carbon. There needs to be just enough perturbation to stimulate plant growth, but not so much as to overwhelm it. Grasses vary, however, in their ability to withstand grazing pressure. Pastures dominated by C4 grasses (such as *Brachiaria* spp.) can support higher grazing intensity while also achieving higher sequestration than grasslands dominated by C3 grasses, which need to be grazed more lightly – which again demonstrates the need to recognise the agro-ecological specifics of the situation. That said and as noted, *Brachiaria* spp. grasslands often receive significant quantities of fertiliser, which leads to problems of nitrogen volatilisation and leaching.

Then there is also the question of animal nutrition. Animals prefer to eat the leaves rather than the stalks of the sward – as the leaf component diminishes, the animals often eat less. In temperate pastures leaves can account for up to 70% of the grass, while in tropical environments leaves can represent 50% or less. Stems of tropical pastures can be very hard and lignified, and animals tend to avoid them unless they are very hungry. This is a crucial factor that limits the intensity of grazing in these regions.

But if the animals graze too lightly, then the woody and weedy plants may encroach, reducing the quality of the forage. And of course, in the absence of any external support such as payments for ecosystem services, farmers will fail to make a living. The theoretical relationships among livestock, forage and land productivity were established decades ago (Box 8).[103]

There is some evidence to suggest that in some cases, grasslands can store more carbon than forests. Thus, keeping ruminants on the land can achieve greater sequestration than removing them altogether and allowing woody vegetation to encroach. But the evidence here is mixed and is unlikely to apply to all grasslands: on many lands, reversion to their natural wooded state will ultimately achieve greater

[102] Chang, J., Ciais, P.K., Viovy, N., Vuichard, N., Herrero, M., Havlik, P., Wang, X., Sultan, S. and Soussana, J.-F. (2016). Effect of climate change, CO_2 trends, nitrogen addition, and land-cover and management intensity changes on the carbon balance of European grasslands. *Global Change Biology,* 22, pp. 338-350, doi: 10.1111/gcb.13050.

[103] Jones, R.J., and Sandland, R.L. (1974). The relation between animal gain and stocking rate: Derivation of the relation from the results of grazing trials *J. agric. Sci*., 83, pp. 335-342.

levels of sequestration than continued grazing.[104,105,106,107,108] It is also important to note, moreover, that grazing animals need not be of the domesticated variety – wild herbivores might be a better option for biodiversity.

In all, the evidence suggests that good grazing management at the right stocking rate certainly helps maintain soil carbon stocks, as compared with poor grazing practice or conversion to cropland. And *in some contexts* grazing can also help sequester carbon, more so than would be achieved by leaving the land without animals. Notably, where soils are degraded, there is generally more scope for improved grazing management to turn things around and build soil carbon than where soils are already in good condition. Thus rangelands generally have a higher potential for grazing-induced sequestration than pastures because their baseline quality tends to be poorer.[109] That said, practical and logistical obstacles may be greater and crucially, there are a whole suite of agro-ecological variables to consider (see discussion below), which in many circumstances will mean that any sequestration achieved is either negligible or season-dependent and season-reversible, or both. Where soils are already in good condition, good grazing management will not sequester much, if any, more carbon, although a switch to poor management or to cropping could cause huge carbon losses.

Some more general provisos, true of all sequestration efforts – whether involving an animal or not – apply. As noted, the benefits of soil carbon sequestration gains are time-limited and there are important issues of permanence, reversibility and leakage to consider. On the plus side, soils rich in carbon have the additional benefit of improving soil fertility and health, so potentially aiding greater agricultural productivity. Additionally, the legacy effects of past management regimes need to be recognised. Sometimes sequestration benefits may be credited to the current grazing regime when the soil carbon accrual may simply reflect a past change in land use – say from cropping to grassland, or from over-grazing to temporary grazing removal. Unless this is recognised, false conclusions about the benefits of a particular management practice may be drawn.

Finally, what is optimal for net sequestration may not be so for biodiversity or for other environmental goals – issues that are explored in more detail in a companion report to this one. Social and economic considerations, not discussed here, add a further layer of complexity.

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[104] Guo, L.B. and Gifford, R.M. (2002). Soil carbon stocks and land use change: a meta analysis. *Global Change Biology* 8(4), pp. 345–360.

[105] Huygens, D., Boeckx, P., Van Cleemput, O., Oyarzu´n, C. and Godoy, R. (2005). Aggregate and soil organic carbon dynamics in South Chilean Andisols. *Biogeosciences* 2(2), pp. 159–174.

[106] Tate, K.R., Scott, N.A., Ross, D.J., Parshotam, A., Claydon, J.J. (2000). Plant effects on soil carbon storage and turnover in a montane beech (Nothofagus) forest and adjacent tussock grassland in New Zealand. *Soil Research* 38(3), pp. 685–697.

[107] Lu, Y.H., Fu, B.J., Feng, X.M., Zeng, Y., Liu, Y., *et al.* (2012). A policy-driven large scale ecological restoration: quantifying ecosystem services changes in the Loess Plateau of China. *PLoS ONE*, 7(2): e31782. doi:31710.31371/ journal.pone.0031782.

[108] Fearnside, P.M., Imbrozio, B.R. (1998). Soil carbon changes from conversion of forest to pasture in Brazilian Amazonia. *Forest Ecology and Management,* 108(1–2), pp. 147–166.

[109] Henderson, B.B., Gerber, P.J., Hilinski, T.E., Falcucci, A., Ojima D.S., Salvatore, and M., and Connant, R.T. (2015). Greenhouse gas mitigation potential of the world's grazing lands: Modeling soil carbon and nitrogen fluxes of mitigation practices. *Agriculture, Ecosystems and Environment,* 207, pp. 91–100.

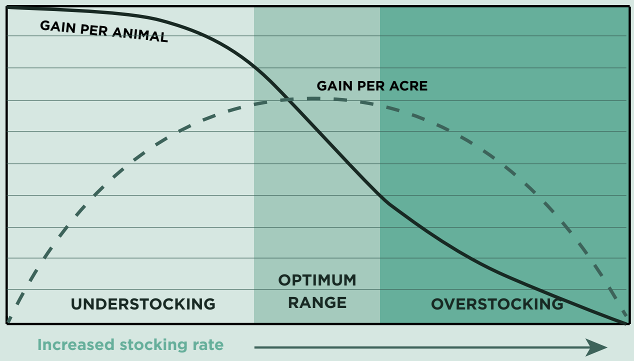
Box 8: The relationship between animal growth, land productivity and forage productivity

In their now classic study, Jones and Sandland (1974) show that the number of animals a given hectare of land can support increases to a critical point after which it plateaus and then declines.[110]

At one animal on a two hectare plot of land, the land's productivity, defined in terms of meat or milk output, is low – not much food output is obtained although the individual animal's productivity may be high. Land productivity can be doubled by stocking with two animals without compromising their individual productivity, provided there is enough forage for both. Further increases may be possible although as the number of animals increases, there will start to be some competition for forage. Figure 8 shows that as more animals are added, *weight gain per animal* may decline since there is more competition for the best forage – but productivity defined *in terms of overall meat or milk output per land area* still increases, since there are more animals overall.

This area-based productivity increase continues to the point where the available forage is depleted by the grazing pressure. From there on, the land's productivity – the ability of the forage to support the meat or milk output achievable at the peak of the curve – starts to decline.

Figure 8: Relationship between livestock stocking rates, livestock and land productivities. Adapted from Jones and Sandland (1974)[111]



This is a slightly oversimplified explanation because at a very low stocking density, the animals may pick off the best species, leaving the less digestible woody species which then start to proliferate and encroach.[112] The quality of the forage declines, which affects the animals' individual productivity. It may therefore be that higher stocking densities will be better for individual animal productivity too – up to a certain point. This observation is an important component of the arguments made by high intensity intermittent grazing enthusiasts (discussed below).

[110] Jones, R.J. and Sandland, R.L. (1974). The relation between animal gain and stocking rate: Derivation of the relation from the results of grazing trials *J. agric. Sci.*, 83, pp. 335-342.

[111] *Ibid.*

[112] Zemmelink, G., Ifar S. and S.J. Oosting (2003). Optimum utilization of feed resources: model studies and farmers' practices in two villages in East Java, Indonesia. *Agricultural Systems,* 76, pp. 77-94.

What is clear, however, is that the balance between the number of animals on the land, and the quantity of vegetation needs to be right. The higher the stocking density, the more abundant the vegetation needs to be to support that density. If animals are heavily grazed to the point that the plants cannot recover then ultimately carbon will be lost from the system: partly because there is less carbon in the biomass itself and partly because the reduction in organic matter and the damage to the sward lessens the soil's capacity to hold itself together – top soils are then blown or washed away. Some of this lost soil will be oxidised to CO_2. Soil degradation also makes it less possible for future generations of plants to grow, meaning the loss of their carbon sequestering effects. Studies assessing the effects of high intensity grazing are in fact few and far between.

Adjusting the timing: rotational grazing, regenerative grazing, mob grazing and its variants

It has been argued by its proponents that high intensity, short duration grazing management (sometimes called intermittent, management-intensive rotational, mob, cell, adaptive or regenerative grazing) can not only achieve greater livestock productivity and health but also sequester significantly more carbon than either continuous grazing management or the removal of animals from the land. This approach underpins some of the most ambitious claims made about the potential that grazing livestock have to 'solve' climate change.[113]

The essence of this suite of related methods is that animals are grazed at very high stocking densities for a short time within a fenced area so that they eat a high fraction of the available vegetation, deposit manure and intensively trample the soil. They are then moved to another area, and then another, and so forth. The grazed land is left to recover before the animals are allowed back on it.

The approach was proposed decades ago,[114] but it has gained visibility as climate change has grown more pressing, and following the influence of its most vocal exponent, Allan Savory (see Box 9), and of popular films such as Carbon Nation.[115] The internet now abounds with blogs, videos and case studies testifying to the benefits,[116] although of course plenty of sceptical voices can also be found.[117,118]

113 Campaign to Protect Rural England (2016). Pasture perfect [online]. http://www.cpre.org.uk/magazine/opinion/item/4224-pasture-perfect (accessed 11.7.17).

114 Briske, D.D., Sayre, N.F., Huntsinger, L., Fernandez-Gimenez, M., Budd, B. and Derner, J.D. (2011). Origin,persistence, and resolution of the rotational grazing debate: Integrating human dimensions into rangeland research. *Rangeland Ecology & Management,* 64(4), pp. 325–334.

115 Carbon nation (2011). Screenings [online]. http://www.carbonnationmovie.com/ (accessed 11.7.17).

116 Chapman, T. (2012). Are mob grazed cattle the perfect arable break? [online]. http://www.nuffieldinternational.org/rep_pdf/1348746792Tom-Chapman-2011-report_.pdf (accessed 11.7.17).

117 The Prairie Ecologist (2011). A Skeptical Look at Mob Grazing [online]. https://prairieecologist.com/2011/11/28/a-skeptical-look-at-mob-grazing/ (accessed 11.7.17).

118 The Guardian. Eat more meat and save the world: the latest implausible farming miracle [online]. https://www.theguardian.com/environment/georgemonbiot/2014/aug/04/eat-more-meat-and-save-the-world-the-latest-implausible-farming-miracle (accessed 11.7.17).

Box 9: Holistic Grazing Management: the Allan Savory approach

Holistic Grazing Management (HGM) is an approach developed by the Zimbabwean biologist Allan Savory and promoted by his Holistic Management Institute. Savory's TED-talk has been viewed over 4 million times[†] and has become a source of inspiration to the grazing movement.

The Savory Institute defines HGM as '*a process of decision-making and planning that gives people the insights and management tools needed to understand nature: resulting in better, more informed decisions that balance key social, environmental, and financial considerations*'.

The Institute hides the very detailed description of the specific practices involved behind a paywall, but central to the overall management approach is the high intensity, intermittent grazing of animals on rotating areas of land (see main text).

However the Institute and Savory himself are emphatic that HGM is not synonymous with the more established practice of rotational grazing (see Table 4 below) as the stocking density and the timings of the rotation are not pre-set, but rather adjusted in response to agro-ecological, and other, variables. The management goals also go beyond animal productivity to encompass environmental and wildlife enhancement. As such it is highly knowledge intensive. There is also the suggestion, by its proponents, that a system's emergent properties deliver meta-benefits over and above the sum of its constituent parts.

† As of September 2017.

The claimed benefits of these regenerative and associated approaches are based on three main tenets. First, is that by grazing at very high stocking densities, the cattle are not able to eat selectively. This means that they eat everything, including less favoured plants. As a result these 'weedier' plants do not have a chance to grow and begin to encroach, which would lower the forage quality. This, it is argued, favours animal nutrition. The grazing of most of the above ground biomass also 'shocks' the plants, causing them to put down deep roots, which means that when they die, the carbon contained lies deep in the soil where it is more likely to be converted into stable forms. Evidence in support of this claim is in fact mixed. Some studies suggest root biomass is reduced following above-ground defoliation. Others show that this approach is associated with both increases and decreases in root mass. Dawson *et al.* (2000) provide a review.[119] As already noted, if the grazing intensity is higher than the plants' ability to recover then ultimately carbon will be lost from the system – a situation seen in overgrazed grasslands across the world.

A second argument that regenerative/intermittent grazing enthusiasts make is that animals' trampling actions break soil crusts, bury carbon in the soil where it is less prone to re-release, and uncover seeds, helping them germinate. Again, the evidence in support of this theory is lacking and as noted in Section 3.4.1 above, a very considerable body of practical evidence finds that the consequences of animal trampling are negative.

119 Dawson, L.A., Grayston, S.J. and Paterson, E. (2000). *Effects of Grazing on the Roots and Rhizosphere of Grasses* in G. Lemaire, J. Hodgson, A. de Moraes, C. Nabinger and P.C. de F. Carvalho (eds). Grassland Ecophysiology and Grazing Ecology. CAB International 2000.

Table 4: Characteristics of rotational grazing, rational grazing and Holistic Planned Grazing. Adapted from Savory Institute (2015)[120]

	Rotational grazing	Rational grazing	Holistic Planned Grazing
Grazing periods are based on:	Number of grazing divisions and desired test period	Recovery periods needed during fast and slow growth	Recovery periods needed during fast and slow growth
Grazing adjustments based on:	Height of grazed plants in grazing division	Daily growth rate of plants	Daily growth rate of plants, livestock performance and/or wildlife needs
Stocking rate is based on:	Estimated dry matter intake and/or rainfall received	Animal days per acre/ hectare (ADA/ADH)	ADA/ADH available for the non-growing season, plus a "time reserve" for drought, and *effectiveness of water cycle*
Animal nutritional needs addressed by:	Estimated dry matter intake and daily monitoring of animals	ADA/ADH estimates and daily monitoring of animals	ADA/ADH estimates, daily monitoring of animals and allocating the best grazing divisions for critical times, then planning backward from those critical periods
Use of herd effect for land restoration:	Not planned	Not planned	Incorporated into plan that is essential in brittle environments
Wildlife and other users/uses:	Not planned	Not planned	Incorporated into plan so livestock can be used to enhance
Drought planned by:	Reserved grazing areas	Reserving time (days of grazing) spread over all grazing divisions	Reserving time in all grazing divisions, and ADA/ADH estimates at end of growing season in a closed plan
Performance in brittle environments:	Breaks down in brittle environments	Breaks down in brittle environments	Does not break down in any environment
Performance in less brittle environments:	Good short term, but likely to break down long term	Good short and long term	Does not break down in any environment
Fire prevention:	Not planned	Not planned	Routinely planned
Management decisions based on:	Multiple goals involving either forage, animals or finances at any one time	Multiple goals involving either forage, animals or finances at any one time	A holistic context that addresses social, environmental and economic factors simultaneously

Regenerative grazing advocates also argue that livestock help build soil carbon via their manure. While there is certainly truth in this, other nutrients, particularly nitrogen, need to be present. This can be achieved by planting legumes (see

[120] Savory Institute (2015). What Is Holistic Planned Grazing? Available at: http://www.savory.global/wp-content/uploads/2017/02/about-holistic-planned-grazing.pdf. Reprinted with permission, Savory Institute, http://savory.global

discussion above as to the pros and cons) but it is worth observing that animals do not add new nitrogen into the grazing system. Many well-known exponents of adaptive regenerative grazing also rear pigs and poultry which then roam the pastures depositing their manure. These animals are fed with externally produced grains, and soy.[121,122] Their faeces, deposited onto the pastures thus introduce additional, but imported nutrients into the farm system. Section 4.2 provides a fuller discussion of the role of nitrogen, and of manure, in relation to the carbon cycle.

Ultimately, it is claimed that these regenerative approaches not only benefit the environment and soil carbon but also enable much higher annual stocking densities (animal numbers per total land area/yr) than continuous ones, the implication being that they are compatible with a plentifully carnivorous diet.

The actual evidence is thin on the ground and contradictory. When it comes to 'conventional' rotational grazing (animals are moved between paddocks either according to calendar dates or after a certain percentage of the sward has been eaten) controlled grazing experiments which have deliberately sought to exclude all variables so as to isolate the effect of the rotation itself, have not found rotational grazing systems to offer carbon sequestration or other advantages over continuous grazing.[123] Savory's response (echoed by others) is, understandably, that by controlling for all the variables, one has in effect thrown the holistic baby out with the bathwater – the whole point of adaptive management is to be aware of, and adapt in accordance with changing variables. But the conclusion that inevitably follows is somewhat tautological: that good managers manage well. Observant, motivated, knowledgeable, highly skilled farmers are more likely to achieve better outcomes on their farms than bad managers. This truism is likely to apply to all farm management approaches, whether based on rotational principles or not. And it also naturally prompts this question: if there are benefits to careful and flexible rotational-type grazing approaches, to what extent can they be rolled out and scaled up? Could just *averagely* motivated farmers ever adopt them successfully?

A comprehensive review by Nordborg *et al.* (2016)[124] which looks at the evidence around adaptive grazing that the Institute itself cites – and by implication 'approves' – actually finds that scientific studies in support of Savory's approach are scanty. Such evidence as exists is generally anecdotal, based on surveys and testimonies rather than on-site measurements. These few studies do indicate some advantages, albeit modest, over continuous approaches, but as the individual studies point in somewhat different directions – that is, one may find benefits for biodiversity but not for soil carbon, while another finds the reverse – the reasons for such advantages as there are, are not entirely clear and it is hard to identify what signal, if any, exists amidst all the noise.

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121 One hundred thousand beating hearts (2016) [online]. https://vimeo.com/170413226 (accessed 11.7.17).

122 Polyface Farms (2017). Pastured Broilers [online]. http://www.polyfacefarms.com/pastured-broilers/ (accessed 8.6.14).

123 Briske, D., Derner, J., Brown, J., Fuhlendorf, S., Teague, R., Gillen, B., Ash, A., Havstad, K. and Willms, W. (2008). Rotational Grazing on Rangelands: An Evaluation of the Experimental Evidence. *Rangeland Ecology and Management,* 61, pp. 3-17.

124 Nordborg, M. (2016). *Holistic Management: a critical review of Allan Savory's grazing methods*. Swedish University of Agricultural Sciences & Chalmers University. Sweden.

Perhaps more importantly, whether or not adaptive grazing approaches offer advantages, it is clear is that the extremely ambitious claims its proponents make are dangerously misleading. The Institute claims that widespread application of its methods would lead to quite massive removals of carbon from the atmosphere – some 500 billion tonnes over 40 years. This would be enough, as it says,[125,126,127] to 'reverse climate change' since about 555 billion tonnes carbon (or 2035 tonnes CO_2) have been released into the atmosphere since the industrial revolution. The Nordborg review[128] dismantles this claim extremely effectively and its conclusions are worth summarising here.

First, Nordborg points out that the sequestration rate of 2.5 t C/ha/yr is substantially higher than all other peer-reviewed estimates (see Section 3.5 below). Second, the amount of grassland to which this is applied, 5 billion hectares, is considerably greater than most estimates of the area of grasslands that can be defined even loosely as grazing lands – Nordborg cites the estimate provided in the IPCC's 2000 report on land use change, of 3.5 billion hectares.[129,130] Third, it is vanishingly unlikely that this constant high sequestration rate could be maintained for 40 years since the rate of accrual diminishes over time as soils approach carbon equilibrium. Finally, Savory does not take into account the significant increases in methane and nitrous oxide that would result from higher livestock numbers.

In many ways, the regenerative approach and its variants can also be seen as a *social* movement, appealing to people who are dissatisfied with conventional practices. Those attracted are often unusually motivated by considerations that go beyond the monetary, and tend to embrace the nuanced approach that is required. Emphasis is placed on community support, knowledge exchange, peer to peer learning and the replacement of inputs with knowledge.[131,132,133,134] While these motivations are clearly laudable, their effectiveness serves to underline the importance of the *social context*

[125] Savory Institute (2013). Restoring the climate through capture and storage of soil carbon through holistic planned grazing – White paper. Available at: http://www.savory.global/wp-content/uploads/2017/02/restoring-the-climate.pdf

[126] Savory, A. (2008). A Global Strategy for Addressing Climate Change. Available at: http://www.savory.global/wp-content/uploads/2017/02/climate-change.pdf

[127] Savory, A. (2013). How to fight desertification and reverse climate change. Available at: https://www.ted.com/talks/allan_savory_how_to_green_the_world_s_deserts_and_reverse_climate_change

[128] Nordborg, M. (2016). *Holistic Management – a critical review of Allan Savory's grazing methods*. Swedish University of Agricultural Sciences & Chalmers University. Sweden. https://pub.epsilon.slu.se/14350/

[129] IPCC (2000). *Land use, land use change and forestry*. Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, R.H., Verardo, D.J. and Dokken, D.J. (Eds.) Cambridge University Press, UK

[130] Henderson, B.B., Gerber, P.J., Hilinski, T.E., Falcucci, A., Ojima D.S., Salvatore, and M., Connant, R.T. (2015). Greenhouse gas mitigation potential of the world's grazing lands: Modeling soil carbon and nitrogen fluxes of mitigation practices. *Agriculture, Ecosystems and Environment,* 207, pp. 91–100.

[131] Hassanein, N. and Kloppenburg, J.R. (1995). Where the grass grows again: Knowledge exchange in the sustainable agriculture movement. *Rural Sociology,* 60(4), pp 721–740.

[132] Weber. K., Heinze, K.L., DeSoucey, M. (2008). Forage for Thought: Mobilizing Codes in the Movement for Grass-fed Meat and Dairy Products, *Administrative Science Quarterly*, 53, pp. 529–567.

[133] Richards, C. and Lawrence, G. (2009). Adaptation and change in Queensland's rangelands: Cell grazing as an emerging ideology of pastoral-ecology. *Land Use Policy* 26(3), pp. 630–639.

[134] Sherren, K., Fischer, J. and Fazey, I. (2012). Managing the grazing landscape: Insights for agricultural adaptation from a mid-drought photo-elicitation study in the Australian sheep-wheat belt. *Agricultural Systems,* 106(1), pp. 72–83.

rather than the merits of any one particular management regime. Regenerative grazing, applied well and by motivated farmers, could well benefit soils, build organic carbon matter and as such perhaps help sequester some carbon. However the overall gains are likely to be modest, are not exclusive to rotational practices, and will be time limited – and the problem of the other greenhouse gases, methane and nitrous oxide – do not go away. There is an important difference between arguing that good adaptive management can improve soil quality and increase soil organic matter – and concluding that it offers the solution to our climate crisis.

Agro-ecological variables: the importance of context

The previous sub-sections have made some general observations about the effectiveness of adjusting the stocking rate and the timing of grazing, and they touched in passing upon the importance of agro-ecological context. The specifics of the agro-ecological context are in fact a critical determinant of sequestration outcomes. Several points here need emphasising.

The first is the sheer variability of grasslands across multiple dimensions. They can be found in the most arid, the wettest, the hottest and the coldest regions of the world. Their soils may be light and porous, or heavy with clay. The animals may spend their time up stony slopes, or in sediment-rich lowlands. The vegetation type will vary enormously and may even include trees. The effects of any particular grazing management regime on livestock productivity will thus be critically determined by the specifics and constraints of climate, rainfall, elevation, soil type, landscape position and vegetation mix. This of course will also be true as to the effects of these factors on soil carbon.

Some of these variables are themselves very changeable – good rainfall will stimulate plant growth and carbon uptake, but a subsequent drought will cause plants to die, soils to dry and soil carbon to be released. Carbons gains made in one season may therefore be reversed in the next.[135]

Of course, humans can modify some of these factors to improve grazing conditions. For example, farmers can irrigate or fertilise grasslands, or sow nutritious or deep-rooted grasses, but these may have environmental downsides as well, such as higher N_2O[136] or energy related emissions, or reduced biodiversity. They can also remove livestock from the system if they need to, by housing or selling them – in which case the environmental impacts at a broader system level need considering.

Table 5 below lists just some of the factors that may affect soil carbon and its accumulation in soils as well as management actions, that might be possible, to influence the outcomes.

[135] Svejcar, T., Angell, R., Bradford, J.A., Dugas, W., Emmerich, W., Frank, A.B., Gilmanov, T., Haferkamp, M., Johnson, D.A., Mayeux, H., Mielnick, P., Morgan, J., Saliendra, N.Z., Shuman, G.E., Sims, P.L. and Snyder, K. (2008). Carbon Fluxes on North American Rangelands *Rangeland Ecol Manage,* 61, pp.465–474.

[136] Jones, S.K., Famulari, D., Di Marco, C.F., Nemitz, E., Skiba, U.M., Rees, R.M. and Sutton, M.A. (2011). Nitrous oxide emissions from managed grassland: a comparison of eddy covariance and static chamber measurements *Atmos. Meas. Tech*., 4, pp. 2179–2194.

Table 5: Factors and their variables that influence the effect of particular grazing practices on soil carbon – a non-exhaustive list.[135]

Agro-ecological factors	Variables that have an effect on soil carbon stores and sequestration rates	Actions that could potentially increase sequestration	Comments and caveats
Climate, rainfall, landscape and elevation	• Temperature, rainfall, extreme weather events (e.g. drought), seasonal fluctuations • Slope of land • Fire risk • Increased atmospheric CO_2 (CO_2 fertilisation effect).	Irrigation and fire management are possible – both have environmental consequences.	Climatic conditions will vary by season, while longer term changes may occur because of climate change. Humid regions have the highest soil carbon sequestration rates followed by arid and temperate rangelands but since arid regions are more extensive in area, the overall potential for sequestration there may be greater.
Soil type, and quality	• Soil type and texture • Current soil carbon stock • Starting conditions – degraded or in carbon equilibrium • Drainage qualities • pH level • Presence or absence of earthworms, fungi, microbes etc. • Organic matter input • Nitrogen and phosphorus levels • Atmospheric N deposition effects.	Soils may be managed for better or for worse: • pH may be altered by liming • The nitrogen content may be influenced by planting legumes, adding manure, and/or applying N fertiliser • Soils may be irrigated • Phosphorus may be added • Soils may be drained • Organic matter may be applied • Areas may be fenced off to reduce damage or allow regeneration.	Generally speaking the worse the initial condition of the land, the greater the scope for improvement. Soils already in good condition are more likely to be in carbon equilibrium. Addition of nitrogen to soils will generate N_2O to the extent that these emissions outweigh any soil carbon gain. Irrigation, liming and fertiliser applications generate fossil fuel associated CO_2 emissions. Organic matter inputs only contribute to net sequestration if they are not being incorporated at the expense of land elsewhere to which the matter was hitherto applied.
Native plant and animal species composition	• Presence of legumes • Whether species have C3 or C4 photosynthetic pathways (affects what happens to their root structures when animals graze them) • Baseline climax vegetation (affects judgements about whether afforestation might be a better option) • Presence of wild herbivores and extent to which they compete for food or water sources.	New plant species may be introduced in order to influence: • Livestock productivity (more digestible species are good for productivity) • Sequestration (deep rooted grasses; C4 versus C3 grasses) • Both livestock productivity and sequestration (legumes improve livestock productivity but also stimulate non legume plant growth and therefore sequestration) • Productivity may be enhanced by using fertilisers or irrigation • Wild herbivores may be removed, managed or preferred.	Introduction of new species may affect biodiversity (the subject of a separate report). Legumes can also cause N_2O release as can the application of synthetic fertilisers. Decreasing fibre content and increasing protein and starch content will decrease emissions from enteric fermentation and manure. Irrigation and synthetic fertilisers also increase energy related emissions. Periodic ploughing for resowing will undo some of the sequestration achieved but increases grassland productivity. Grazing intensity is positively correlated with sequestration in C4 grasslands and negatively in C3 grasslands. Where the baseline climax vegetation was originally forest, rewilding might achieve greater levels of sequestration. Removal of wild herbivores raises numerous environmental questions: preferring them to livestock means that decisions have to be made about what to do with the 'foregone' meat.

Agro-ecological factors	Variables that have an effect on soil carbon stores and sequestration rates	Actions that could potentially increase sequestration	Comments and caveats
Land area available	• Animal numbers/ha/yr • Animal type or species mix (influences grazing and trampling patterns) • Timing of grazing • Objective: management for biodiversity, for carbon sequestration, for livestock productivity or for profit • External sources of nutrition and housing.	Stocking densities will need to match the carrying capacity of the land, taking into account seasonal and climatic variations. Numbers may be adjusted on a given area of land to suit forage availability and climatic conditions. If reductions in grazing pressure are needed to reduce foraging pressure, land needs to be available to move the animals to or they will need to be housed and fed with supplementary feed – or sold on. Different species or combinations of animal species with different grazing effects may be introduced. The intensity and timing of grazing may be altered. Depending upon context, measures may include: • Increasing stocking rates where biomass is abundant) to increase 'cutting frequency' of the grass • Reducing stocking rates where land is overgrazed • Stocking only at certain times, often at high densities (may be referred to as rotational, cell, adaptive or intermittent), interspersing with periods of rest.	Direct animal emissions (methane and nitrous oxide) need to be set against any sequestration arising. Note that management regimes based on higher livestock numbers will need to achieve more sequestration to offset higher methane and nitrous oxide emissions. There may be synergies between goals to improve sequestration, animal productivity and profit, but there can also be tradeoffs. Where feed is supplemented, the direct and indirect GHG impacts of feed production need to be accounted for. If animals are sold on, the environmental impacts associated with the system they enter need to be accounted for.

Ultimately,[137] there are some fundamental limitations on what humans can or cannot do, meaning that light grazing in one region will be too heavy in another, and meaning also that in many parts of the world, it will simply not be possible to achieve any substantive increase in soil carbon.

A meta-analysis of the effects of grazing on grassland soil carbon indeed confirmed the importance of the specifics of the agro-ecological context.[138] The study showed that six main variables: soil texture, precipitation, grass type, grazing intensity, study duration, and sampling depth explained 85% of the (large) variance in the rate of sequestration. It also found that no easy judgements can be made about the relationship between grazing intensity and any single factor such as rainfall or soil type. That said, the authors do suggest that a combination of C_4 grasses and higher grazing intensity can lead to higher soil carbon gains (although see the points about animal nutrition in 3.4.c above) – and that the reverse is true on C_3 grasslands. Significantly, they note that the effects of grazing management on SOC can be large *in both directions*, with equally distributed gains or losses of about 5.5 t CO_2/ha/yr (1.5 t C/ha/yr). Note too that initially high sequestration rates will diminish over time.

Of course, there will also be social, institutional, intellectual, technical and economic influences on the feasibility and consequences of any one course of action. These include the availability and affordability of inputs, labour, investment and capital; the support or otherwise of institutions and policies; access to transport and other communications; configurations of land tenure and use; cultural mores and traditions; knowledge, mindsets and motivations.

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[137] McSherry, M.E. and Ritchie, M.E. (2013). Effects of grazing on grassland soil carbon: a global Review, *Global Change Biology,* 19, pp. 1347–1357, doi: 10.1111/gcb.12144

Kell, D.B. (2011). Breeding crop plants with deep roots: their role in sustainable carbon, nutrient and water sequestration, *Annals of Botany,* 108: pp. 407–418.

Henderson, B.B., Gerber, P.J., Hilinski, T.E., Falcucci, A., Ojima D.S., Salvatore, and M., Connant, R.T. (2015). Greenhouse gas mitigation potential of the world's grazing lands: Modeling soil carbon and nitrogen fluxes of mitigation practices. *Agriculture, Ecosystems and Environment,* 207: pp. 91–100.

Abberton, M., Conant, R. and Batello, C. Eds. (2010). *Grassland carbon sequestration: management, policy and economics* – Proceedings of the Workshop on the role of grassland carbon sequestration in the mitigation of climate change. Integrated Crop Management. Rome, Italy, Food and Agriculture Organisation of the United Nations FAO.

Booker, K., Huntsinger, L., Bartolome, J.W., Sayre, N.F. and Stewart, W. (2013). What can ecological science tell us about opportunities for carbon sequestration on arid rangelands in the United States? *Global Environmental Change,* 23(1): pp. 240–251.

FAO (2010). *Challenges and opportunities for carbon sequestration in grassland systems*. Integrated Crop Management. Rome, Italy, Food and Agriculture Organisation of the United Nations FAO. p. 9.

Lemaire, G., Hodgson, J. and Chabbi, A. Eds. (2011). *Grassland Productivity and Ecosystem Services*, CAB International CABI.

Michalk, D.L., Millar, G.D., Badgery, W.B. and Broadfoot, K.M. Eds. (2013). Proceedings of the 22nd International Grassland Congress.

Soussana, J., Tallec, T. and Blanfort, V. (2010). Mitigating the greenhouse gas balance of ruminant production systems through carbon sequestration in grasslands. *Animal,* 4(3): pp. 334–350.

Kebreab, E., Strathe, A., Fadel, J., Moraes, L. and France, J. (2010). Impact of dietary manipulation on nutrient flows and greenhouse gas emissions in cattle. *Rev. Bras. Zootecn*. 39: pp. 458–464.

[138] McSherry, M.E. and Ritchie, M.E. (2013). Effects of grazing on grassland soil carbon: a global review. *Global Change Biology,* 19, pp. 1347–1357, doi: 10.1111/gcb.12144

3.5 Some numbers: what level of sequestration could ruminants in grazing systems achieve? And how significant is this compared to other land-based approaches?

As the previous section showed, with good grazing management, some level of sequestration is possible on some lands, but there are multiple provisos across multiple dimensions to consider. This section attempts to more quantitatively assess what the potential might be at a global level.

It begins by reviewing some of the global estimates that can be found, both in the peer-reviewed and non-peer-reviewed literature, of sequestration potential per hectare.

Next, it adds on the question of animal emissions. Grazing animals may stimulate sequestration on a given piece of land but they also generate methane and nitrous oxide emissions. Put one way, for a given number of animals, a certain level of sequestration will be needed to offset these other emissions. Put another way, for a certain level of sequestration a certain number of animals is 'affordable'. The higher the stocking rate, the higher the rate of sequestration needs to be. What is this relationship and how does it change over time?

The final section (Section 3.5.3) puts these numbers in the context of livestock emissions as a whole: where we need to be, emissions-wise if we are to meet the UN Paris Climate Agreement target, and the sequestration potential from land-based sectors as a whole.

3.5.1 Global estimates of the grazing related soil carbon sequestration potential

While there are many estimates as to the sequestration potential achievable at a field or fairly local level, larger scale regional or global estimates are relatively few and far between.

Figure 9 shows the mean values taken from those that have been published. While we may not have captured every published study on this topic, we do include estimates from papers that are themselves comprehensive reviews, such as Conant *et al.* (2001)[139] and Conant *et al.* (2017).[140] As such, the figure provides a reasonable representation of the published range. The estimates shown in black are from peer-reviewed studies; we also include two used by the Savory Institute to show the difference. Some of the practices illustrated, such as legume sowing, strictly speaking relate to grassland management, rather than grazing management. Emissions arising from the livestock themselves or from other management practices such as legume sowing are not taken into account.

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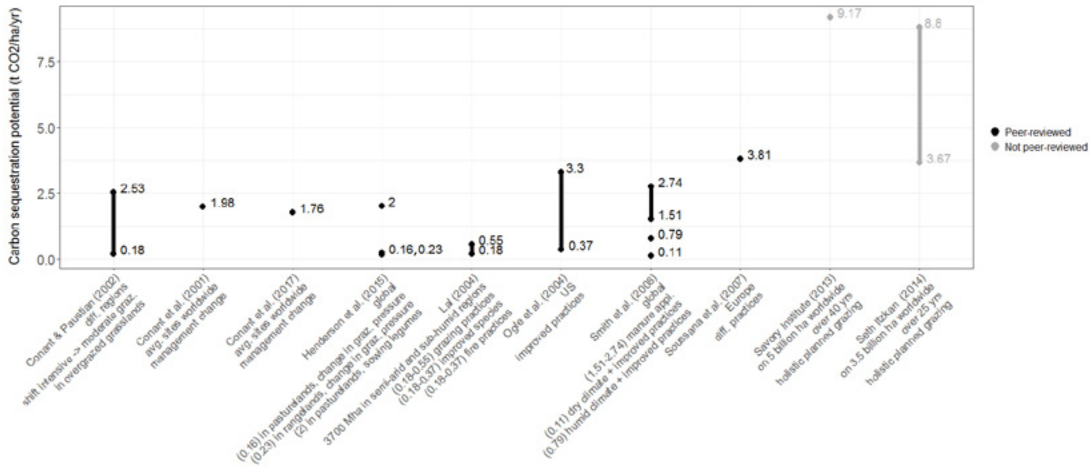
[139] Conant, R.T., Paustian, K. and Elliott, E.T. (2001). Grassland management and conversion into grassland: effects on soil carbon. *Ecological Applications,* 11, pp. 343–355.

[140] Conant, R.T., Cerri, C.E.P., Osborne, B.B. and Paustian, K. (2017). Grassland management impacts on soil carbon stocks: a new synthesis. *Ecological Applications*, 27(2), pp. 662–668.

Figure 9: Estimated annual soil carbon sequestration potential from grazing management, per hectare[141]



Note: Conant et al. (2017) also provide a higher estimate, putting the total potential at 1.89 tonnes CO_2-eq/yr (up from the 1.76 shown). This higher estimate includes conversion from cropping to pasture (which increases soil carbon) and from native vegetation to pasture changes that would potentially undermine food security objects, and in the case of native vegetation conversion, would reduce biodiversity.

Most of these papers include multiple data points reflecting different sites or practices; mean values are shown here.

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[141] Conant, R.T., and Paustian, K. (2002). Potential soil carbon sequestration in overgrazed grassland ecosystems. *Global Biogeochemical Cycles*, 16(4), pp. 1-9. Available at: https://doi.org/10.1029/2001GB001661

Conant, R.T., Paustian, K., and Elliott, E.T. (2001). Grassland Management and Conversion Into Grassland: Effects on Soil Carbon. *Ecological Applications*, 11(2), pp. 343–355. Available at: http://www.esajournals.org/doi/abs/10.1890/1051-0761%282001%29011%5B0343%3AGMACIG%5D2.0.CO%3B2

Conant, R.T., Cerri, C.E.P., Osborne, B.B., and Paustian, K. (2017). Grassland management impacts on soil carbon stocks: a new synthesis. *Ecological Applications*, 27(2), pp. 662–668. Available at: https://doi.org/10.1002/eap.1473

Henderson, B., Gerber, P.J., Hilinski, T.E., Falcucci, A., Ojima, D.S., Salvatore, M., and Conant, R.T. (2015). Greenhouse gas mitigation potential of the world's grazing lands: Modeling soil carbon and nitrogen fluxes of mitigation practices. *Agriculture, Ecosystems & Environment*, 207, pp. 91–100. Available at: https://doi.org/10.1016/j.agee.2015.03.029

Lal, R. (2004). Soil carbon sequestration to mitigate climate change. *Geoderma*, 123, pp. 1–22. Available at: http://www.sciencedirect.com/science/article/pii/S0016706104000266

Ogle, S.M., Conant, R.T., and Paustian, K. (2004). Deriving grassland management factors for a carbon accounting method developed by the Intergovernmental Panel on Climate Change. *Environmental Management*, 33(4), pp. 474–484. https://doi.org/10.1007/s00267-003-9105-6

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., … Smith, J. (2008). Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, 363, pp. 789–813. https://doi.org/10.1098/rstb.2007.2184

Soussana, J.F., Allard, V., Pilegaard, K., Ambus, P., Amman, C., Campbell, C., … Valentini, R. (2007). Full accounting of the greenhouse gas (CO2 , N2O , CH4) budget of nine European grassland sites. *Agriculture, Ecosystems and Environment*, 121, pp. 121–134. https://doi.org/10.1016/j.agee.2006.12.022

Itzkan, S. (2014). Upside (Drawdown) The Potential of Restorative Grazing to Mitigate Global Warming by Increasing Carbon Capture on Grasslands. Available at: http://www.planet-tech.com/upsidedrawdown

Savory Institute (2013). Restoring the climate through capture and storage of soil carbon through holistic planned grazing – White paper. Available at: http://www.savory.global/wp-content/uploads/2017/02/restoring-the-climate.pdf

The range in estimates is evidently large: this reflects not just the uncertainties inherent in making estimates of this type, but also differences in what management practice are considered, the geographical and agro-ecological focus of the studies and methods of data acquisition or generation – including the time-frame over which the sequestration rate is averaged. In other words, these numbers are underpinned by multiple and different assumptions. Annex 2 provides further details.

Important to note is that while the studies show averages *per hectare*, it would be very misleading to extrapolate from these the *absolute* sequestration potential – that is, to multiply a per hectare value by an estimate of the total grazing land area, which as Section 1.3 showed is itself subject to huge uncertainties. Conant *et al.* (2017)[142] underlines this point and makes additional observations that are worth quoting:

> *'… these results do not apply uniformly to all grazing lands and extrapolating the results of this synthesis regionally or globally requires information about where there is scope for improvement of grassland management … Also, despite our estimate of an average increases in soil C stocks with grazing improvement, it is not always the case that improved grazing management leads to increased soil C stocks. Even when it does, soil C stock responses vary as a function of climate, soil, and vegetation characteristics.'*

To illustrate, it would not be accurate to multiply 1.7 tonnes CO_2 (Conant *et al.* (2017)'s average per hectare figure) by 2600 Mha, or 3200 Mha or any other of the uncertain estimates one chooses to use of the global grazing land area, as it is not possible to achieve such sequestration rates on all grazing lands.

Notably too, all the peer-reviewed studies fall below 4 t CO_2/ha/yr, with a mean of about 1.8 t CO_2/ha/yr (or 0.5 t C/ha/yr). As Section 3.5.3 below will discuss, in the grand scheme of things this potential, while useful, is modest.

The non-peer-reviewed estimates from the Savory Institute are strikingly higher – and, for all the reasons discussed earlier (Section 3.4.3), unrealistic. Some very high sequestration rate claims can also be found in anecdotal literature on the internet. Leaving aside the technical challenges involved in accurately quantifying soil carbon changes (see Box 6 above), one explanation for these optimistic claims could be the fact that in the early years of a change in practice, sequestration rates may indeed be high. But the rate dwindles over time and so the changing sequestration rate over a period of time – such as 40 years – needs to be accounted for.

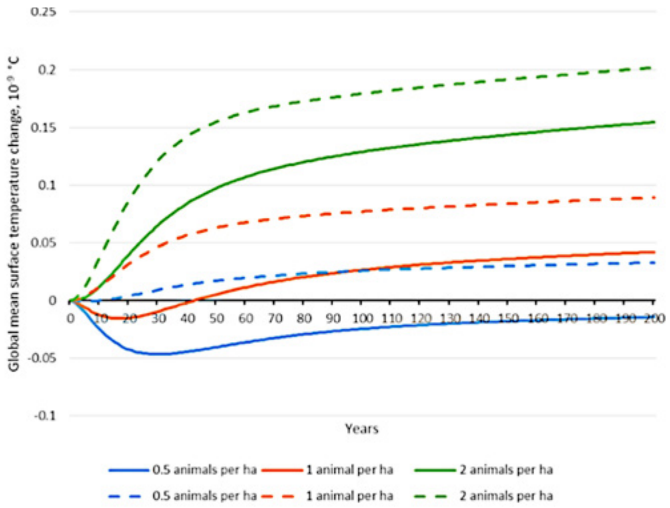
3.5.2 Soil carbon sequestration versus methane emissions

While in some contexts grazing management can cause soils to sequester carbon, the grazing livestock themselves emit enteric methane as well as methane and nitrous oxide through their dung and urine. For a given number of animals per hectare producing a certain level of greenhouse gases, a certain level of carbon sequestration is needed to offset them. Or, put another way, for a given level of sequestration, a certain quantity of methane and nitrous oxide is 'allowable'. Since the rate of sequestration slows as soils approach carbon equilibrium, this relationship changes over time.

[142] Reference?

Figure 10 illustrates the point for methane and for carbon sequestration only – nitrous oxide emissions are not represented but in many grazing land contexts, its inclusion would make it harder for sequestration to outweigh emissions.

Figure 10: Theoretical relationships between animal stocking rates, methane emissions, sequestration rates and time and change in global mean surface temperature



Temperature change over two hundred years from yearly emissions of methane from enteric fermentation in cattle (50 kg CH_4 per animal a year) and two different theoretical carbon sequestration rates in soils; for solid lines carbon sequestration starts at 3 tonnes carbon sequestered per years (average sequestration rate 0.7 t C/yr) and for dotted lines carbon sequestration starts at 1 tonne carbon sequestered per year (average sequestration rate 0.2 t C/yr), both rates declining exponentially down to close to 0 over 50 years as soils reach equilibrium. An average carbon sequestration rate of 0.7 t C/yr for 50 years can offset the temperature increase caused by methane during this period with a stocking rate of 0.5, while for a stocking rate of 1, an average carbon sequestration rate of 0.7 t C/yr can only offset warming from methane emissions for approximately 40 years. Note, that the C sequestration rates shown here correspond to very high rates over a long period of time and these should be considered as extremely optimistic.

The climate impacts of CH_4 and CO_2 were modelled over time using the same expressions for relating emissions of GHGs to changes in atmospheric concentrations and resulting radiative forcing as the IPCC uses for calculating GWPs and GTPs (Myhre et al. *2013;*[143] *Persson* et al. *2015*[144]*). The model simulates the radiative forcing trajectory and corresponding global mean surface temperature change of a certain amount of CO_2 or CH_4. It uses the same set of assumptions regarding the radiative efficiency and atmospheric lifetimes of the GHGs as used by IPCC AR5.*

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143 Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang. (2013). *Anthropogenic and Natural Radiative Forcing*. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

144 Persson, U.M., Johansson, D.J.A., Cederberg, C., Hedenus, F. and Bryngelsson, D. (2015): Climate metrics and the carbon footprint of livestock products: Where's the beef? *Environmental Research Letters*, 10(3).

Myhre, G., Shindell, D., Bréon, F.-M., Collins, W., Fuglestvedt, J., J. Huang, D.K., Lamarque, J.-F., Lee, D., Mendoza, B., Nakajima, T., Robock, A., Stephens, G., Takemura, T., H. Zhang. (2013). *Anthropogenic and Natural Radiative Forcing,* In: Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

The figure shows that the overall effect on the net GHG balance will depend upon the rate of sequestration, the number of years for which sequestration occurs before soils reach carbon equilibrium, and the stocking rate. All these factors will of course be determined by the highly context-specific agro-ecological variables discussed in Section 3.4 above. Note that this is only a schematic diagram that sets out the *principle* of the relationships between animal numbers, sequestration rates, emission factors and time. It should not be taken to mean for instance, that at 0.5 animals per hectare, the effect is always one of net removals. In addition to the specifics of climate, soils and so forth, different sequestration rates or time periods could have been chosen; in many contexts soils will reach equilibrium within 20 years, not 50, and the quite high sequestration rates used here will be either unachievable in many regions or only possible with additional inputs such as feed supplementation or fertiliser applications, which will generate additional emissions. To underline the point: it by no means illustrates what a farm stocking at, say, one animal per hectare is likely to be able to sequester.

3.5.3 The role of grazing ruminants in the net GHG balance – what can we conclude?

Taking grazing animal emissions on the one hand; and their sequestration potential on the other, can we draw any conclusions about the net GHG balance? And how significant is the resulting number when compared with the scale of the emissions problem?

While various estimates of the global sequestration potential achievable from changes in grazing management have been made, many have not undergone peer review. Here we consider two that have done so, and so that we illustrate the extremes: Henderson *et al.* (2015)[145.] (discussed earlier in this chapter) estimate the biophysical sequestration potential to be 295 Mt CO_2/yr; Smith *et al.* (2008)[146] who assess the economic potential, calculate that with a very high level of mitigation ambition sequestration potential could be as high as 800 Mt CO_2-eq/yr. Smith *et al.* (2008)'s estimate includes the application of practices such as fire management, nutrient management and adjustments to the grazing intensity.

The Smith *et al.* (2008) estimate is plotted in Column 1 of Figure 11 below – the Henderson *et al.* (2015) estimate will be about a third of this. We additionally show the estimates cited by the Savory Institute to illustrate their vast discrepancies with the peer-reviewed values.

We set the estimated sequestration potential (Column 1) against current annual emissions from grazing ruminants (Column 2) – about 1.32 Gt CO_2-eq or 20% of the livestock total.[147] The third column shows the net of emissions and potential removals:

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[145] Henderson, B.B., Gerber, P.J., Hilinski, T.E., Falcucci, A., Ojima D.S., Salvatore, and M., Connant, R.T. (2015). Greenhouse gas mitigation potential of the world's grazing lands: Modeling soil carbon and nitrogen fluxes of mitigation practices. *Agriculture, Ecosystems and Environment,* 207, pp. 91–100.

[146] Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M. and Smith, J. (2008). Greenhouse gas mitigation in agriculture. *Philos Trans R Soc*, 363(1492), pp. 789–813.

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

even assuming the maximum mitigation potential, the grazing sector would continue to be a net emitter (and it is even more of a net emitter today).

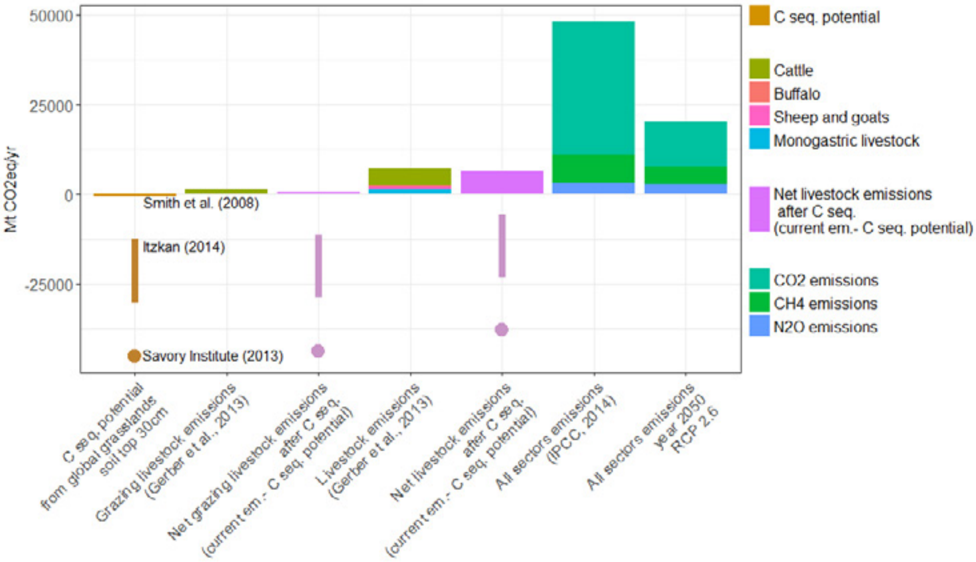
At this point, it is also essential to recall that the grazing sector's contribution to overall meat and milk output is very low indeed at 13% of ruminant meat and 6% of ruminant milk – and the ruminant sector as a whole contributes less than half of overall animal protein supply (Section 1.2). It would be physically impossible for the animal protein production produced today – about 27 g/person/day – to be supplied by grazing systems, at least without an unthinkably damaging programme of forest clearance, which would vastly increase the livestock sector's already large (at 7 Gt CO_2-eq) contribution to global GHG emissions. This is why the figure also shows the emissions from the livestock sector as a whole (Column 4); and the net result (Column 5) when the potential sequestration effect achieved through grazing management is included. What all this clearly illustrates is that if we want to continue to eat animal products at the levels we do today, then the livestock sector will continue to be a very significant emitter of GHGs. Grazing management, however good, makes little difference. These points are discussed more fully in Chapter 4.

The sixth column shows annual global GHG emissions from all sources – agriculture, transport, the built environment and so forth, to which livestock contributes about 15%. The final column shows the maximum allowable annual emissions from all sources that are consistent with the target to limit the global rise in temperatures to no more than 2°C above pre-industrial levels, as set out in the Paris Climate Accord. Staying within the more stringent 1.5°C limit would of course require emissions to be lower still.

What this figure also so strikingly shows is that even assuming a very optimistic peer-reviewed estimate of the grazing-related sequestration potential (Smith *et al.*, 2008),[148] the contribution it could make to the overall scale of the mitigation challenge looks tiny.

[148] Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M. and Smith, J. (2008). Greenhouse gas mitigation in agriculture. *Philos Trans R Soc*, 363(1492), pp. 789-813.

Figure 11: Grazing ruminants, their emissions, their sequestration potential and the 2°C warming limit[149]



Note: Smith et al. *(2008) in Column 1 is the most optimistic one found in the peer-reviewed literature and puts the potential at 800 Mt CO_2/yr. Grazing animal GHG emissions (columns 2 and 3) includes emissions attributed to milk and meat (sheep and goats as well as cattle and buffalos, although cattle and buffalos account for almost all the impacts) and to land use change but excludes post-harvest emissions. Columns 4 and 5 includes emissions attributable to edible products, to other goods and services, such as draught power and wool and includes post-harvest emissions.*

Note: Grazing systems are defined as in Seré and Steinfeld (2006)[150] *– see Table 2 Section 1.1 of this report.*

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149 Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M. and Smith, J. (2008). Greenhouse gas mitigation in agriculture. *Philos Trans R Soc*, 363(1492), pp. 789–813.

Itzkan, S. (2014) Upside (Drawdown) The Potential of Restorative Grazing to Mitigate Global Warming by Increasing Carbon Capture on Grasslands. Available at: http://www.planet-tech.com/upsidedrawdown.

Savory Institute (2013) Restoring the climate through capture and storage of soil carbon through holistic planned grazing – White paper. Available at: http://www.savory.global/wp-content/uploads/2017/02/restoring-the-climate.pdf

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

IPCC (2014) *Summary for Policymakers*. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

van Vuuren, D.P., Eickhout, B., Lucas, P.L., and den Elzen, M.G.J. (2006). Long-term multi-gas scenarios to stabilise radiative forcing – Exploring costs and benefits within an integrated assessment framework. *Multigas Mitigation and Climate Policy*. The Energy Journal Special Issue. pp.201–233.

van Vuuren, D., den Elzen, M., Lucas, P., Eickhout, B., Strengers, B., van Ruijven, B., Wonink, S. and van Houdt, R. (2007). Stabilizing greenhouse gas concentrations at low levels: an assessment of reduction strategies and costs. *Climatic Change*, doi:10.1007/s/10584-006-9172-9.

150 Seré C. & Steinfeld S. (1996). World livestock production systems: current status, issues and trends. FAO Animal Production and Health Paper 127. Food and Agriculture Organisation, Rome.

It is also helpful to set this potential in the context of the overall sequestration potential of the entire land-based sector. Here too, estimates are subject to enormous uncertainties (see Box 10) and so the range in estimates is correspondingly large.

As an example of a highly aspirational target, the global, multi-stakeholder 4 per 1000 initiative[151] states that 4.4 Gt CO_2 (1.2 Gt C) could be stored every year in agricultural soils.[152] The highly aspirational nature of this target needs to be emphasised given the numerous practical as well as environmental constraints, not least of which is nutrient availability.[153]

Smith (2016) estimates the economic potential (at carbon prices of between 20 and 100 US$/t CO_2-eq) from the land-based sector as a whole to be a more modest 1.5-2.6 Gt CO_2/yr, again for all agricultural soil types[154]. These estimates also include the sequestration potential from croplands: since carbon stores in these soils are often very low, the potential for improvement there is significant, and worth emphasising given the heightened attention given to grazing lands.

To put the grazing estimates into perspective: depending upon which grazing-based estimates and which land-based estimates are used, the sequestration potential from changed grazing practice would account for 7–53% of the total land-based sequestration potential. The 7% figure uses the Henderson *et al.* (2015) grazing estimate (the most pessimistic at 295 Mt CO_2/yr) and calculates its contribution to the the 4 per 1000 land-based sector estimate of 4.4 Gt CO_2/yr (the most optimistic). The 53% figure is based on using the high estimate by Smith *et al.* (2008) for the grazing sequestration potential (800 Mt CO_2-eq/yr) and the lowest estimate of the total land-based sequestration potential from Smith *et al.* (2016).

While the range is huge and its importance to the total land-based sequestration total could be quite significant depending on the estimate chosen, in absolute terms these are small numbers. Total annual global GHG emissions from all sources stand at approximately 49 Gt CO_2-eq/yr.[155] Evidently, land-based sequestration approaches of whatever kind, while useful, can only play a minor part in getting emissions down to where they need to be.

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[151] 4 pour 1000 (2017). Understand the “4 per 1000” initiative [online]. http://4p1000.org/understand (accessed 11.7.17).

[152] UNFCCC (undated). Join the 4 per 1000 Initiative: Soils for food security and climate [online]. http://newsroom.unfccc.int/lpaa/agriculture/join-the-41000-initiative-soils-for-food-security-and-climate/ (accessed 11.7.17).

[153] van Groenigen, J.W., van Kessel, C., Hungate, B.A., Oenema, O., Powlson, D.S. and van Groenigen, K.J. (2017). Sequestering Soil Organic Carbon: A Nitrogen Dilemma. Environ. *Sci. Technol.*, 51, pp. 4738−4739.

[154] Smith, P. (2016). Soil carbon sequestration and biochar as negative emission technologies. *Global Change Biology,* 22, pp. 1315-1324. doi: 10.1111/gcb.13178.

[155] IPCC (2014) *Summary for Policymakers*. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Box 10: Uncertainties in calculating the sequestration potential of the land-based sector as a whole

There have been numerous and fairly divergent estimates of how much land-based sequestration is possible overall, both through management regimes that involve livestock and those that do not. The disparities may arise because they estimate the total land area differently, or because studies focus on different land types in different agro-ecological contexts – some consider only the potential for drylands, and others just temperate grasslands. Studies also differ in how, or how far they extrapolate the sequestration rates applied from one particular geographical location to all lands that broadly fit that agro-ecological category. Some estimate the technical or biological potential for sequestration; others focus on what they consider to be the *economic potential*, that is, the sequestration that could be realised at a given carbon price; others focus on what is considered *feasible* based on, for example, what technologies are available in a given region. Often a paper or report will cite a figure based on a previous study, without explaining why they chose it.

Adding to the confusion, different units of measurement may be used: some assess the sequestration potential per hectare per year; others overall absolute annual sequestration rates; while others still estimate the overall sequestration potential over a period of years. Different assumptions about methods used are also made, in order to measure the decrease in the rate of sequestration as a new equilibrium is approached.

4. The other greenhouse gases: methane and nitrous oxide

Key points: methane

- Methane has a high global warming potential but short atmospheric life span, as compared with carbon dioxide, with its weaker forcing effect and very long atmospheric life time.
- Because of these differences, methane's importance as a priority for mitigation is the subject of debate. From one perspective, prioritising methane reduction offers a 'quick win', but from another, it could distract us from our fossil fuel dependence and associated CO_2 emissions.
- This debate can become ideologically driven since ruminants are responsible for a third of all anthropogenic methane, with grazing systems particularly methane intensive per kg of product.
- Some stakeholders place strong emphasis on the transitory warming effects of methane, others on its potency.
- While a given pulse of methane may be transitory, warming will continue as long as the source of methane continues – if ruminants continue to be reared, methane will continue to be emitted, with its associated warming effects.
- The livestock sector is also an important source of CO_2. Systems with grassfed ruminants can be highly dependent on fossil fuels at levels comparable to intensive pork and poultry production. Livestock, including grazing livestock, also drive CO_2 release via deforestation and land degradation.
- Efforts at reducing the methane intensity of ruminant production through feeding and breeding strategies and the use of additives have limited impacts and are outweighed by the effects of increased animal numbers.
- It follows that achieving absolute cuts in methane emissions will require a halt on further increases in animal numbers.

Key points: nitrous oxide

- Nitrous oxide is both an extremely potent and relatively long lived greenhouse gas.
- All livestock, including ruminants, cause nitrous oxide emissions via their excreta, although the amount varies by animal type, production system and approach to manure management.
- Nitrogen is essential for plant growth. There needs to be sufficient available nitrogen for plants to grow; and plants need to grow if carbon is to be sequestered in soils.

- While livestock play a role in nitrogen cycling by ingesting nitrogen in the form of plant matter and returning some of it to soils via their excreta they add no new nitrogen to the system. Ultimately the system loses nitrogen via leakage and volatilisation and in the form of exported animal carcasses or milk.
- This nitrogen needs replacing through the use of fertilisers or legumes, or the animals need to be reared at rates low enough to enable the natural process of nitrogen replenishment (via naturally present legumes and soil bacteria) to proceed. This implies very low stocking rates.
- Low rates of plant growth, resulting from insufficient nitrogen availability mean low rates of soil carbon sequestration. Soil carbon sequestration therefore depends on the presence of sufficient nitrogen.
- Since nitrous oxide is a potent greenhouse gas, nitrous oxide emissions can sometimes outweigh the benefits of soil carbon sequestration. The trade-offs will be highly context-specific.

Despite any sequestration benefits achievable through grazing system management, Chapter 3 finds that the livestock sector as a whole, including the grazing subsector, is a significant net source of GHG emissions. Nitrous oxide emissions account for about 30% of the ruminant emissions total, but what marks ruminants out from other animal types is the additional importance of methane[†] which accounts for nearly half of the all ruminant emissions, largely via enteric fermentation.[156]

[†] All animals contribute methane via their manure, but ruminants are by far the largest contributors to overall methane emissions because of their contribution via enteric fermentation, which substantially outweighs manure related emissions.

CO_2 is also significant, particularly if historical and continuing land use change-related CO_2 is taken into account. It is discussed further in Chapter 5; this Chapter considers the two other gases, methane and nitrous oxide, and some of the claims and counterclaims made about them in relation to grazing systems.

4.1 How much does methane matter? Different approaches to calculating methane's impact

Methane has two qualities that go in opposite directions, at least as far as climate policy is concerned. On the one hand, the gas has a high global warming potential, substantially higher than CO_2 in the short term. On the other, it has a short atmospheric lifetime. So, is it a problem… or not? Stakeholders differ in how they weight these two aspects when engaging in the livestock debate.

Many environmentalists and animal welfare and rights advocates place strong emphasis on methane's high near term warming impacts, arguing that action to reduce methane should feature heavily in climate mitigation efforts as it accounts for 16% of the total warming effect – of which ruminant emissions comprise a third.[157] Tackling

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

[157] IPCC (2014) *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

methane offers a 'quick win' that effectively buys us time to do the very difficult job of decarbonising the global economy.[158, 159,160] Some – although certainly not all – within the environmental movement suggest that if one must eat animal products, then it is preferable to choose those from monogastric animals such as pigs and poultry.

Box 11: What scope is there to reduce methane emissions through livestock management?

Ways of reducing the methane intensity of ruminant systems include: changing the nutritional make up of feed rations (whether fodder or concentrate based); breeding more productive livestock (fewer animals needed per unit of production, or more output relative to constant animal numbers); combatting diseases (for the same reason); and better manure management. Some of these incur trade-offs involving the nitrogen and/or carbon cycle. For example, animals that eat more digestible feeds – that is, feeds with a better balance of digestible carbohydrates and proteins – tend also emit fewer methane emissions relative to their milk or meat output. But the production of more digestible feeds often entails the use of fertilisers or the production of legumes, which can increase nitrous oxide fluxes.

There are other options too that are either controversial (for example the use of growth promoters such as bovine somatotropin), affect milk quality negatively, have side effects or are ineffective in the long-run (for example the use of feed additives).[161,162,163] There has for example been a recent flurry of interest in using seaweed to reduce enteric methane.[164] However, the gut microflora tends to evolve rapidly and it appears that the potential for future efficiency improvements to deliver the absolute reductions in emissions that are needed is limited. Of course the future has a habit of delivering surprises so wildcard innovations are always a possibility.

Others, including those drawn from the grazing advocacy movement, challenge this way of thinking. At one level, they may argue that the sequestration benefits compensate for the methane cost – a claim that was discussed in Chapter 3.

158 Scovronick, N., Dora, C., Fletcher, E., Haines, A. and Shindell, D. (2015). Reduce short-lived climate pollutants for multiple benefits. *Lancet*, 386(10006):e28-31. doi: 10.1016/S0140-6736(15)61043-1.

159 Jardine, C.N., Boardman, B., Osman, A., Vowles, J. and Palmer, J. (undated). *Methane*, UK Environmental Change Institute, University of Oxford.

160 Ramanathan, V. and Xu, Y. (2010). The Copenhagen Accord for limiting global warming: criteria, constraints, and available avenues. *Proc. Natl. Acad. Sci. USA,* 107, pp. 8055-8062. doi: 10.1073/pnas.1002293107.

161 Knapp, J.R., Laur, G.L., Vadas, P.A., Weiss, W.P. and Tricarico, J.M. (2014). Invited review: Enteric methane in dairy cattle production: Quantifying the opportunities and impact of reducing emissions. *Journal of Dairy Science*, 97(6), pp.3231–3261.

162 Hristov, A.N., Oh, J., Firkins, J.L., Dijkstra, J., Kebreab, E., Waghorn, G., Makkar, H.P.S., Adesogan, A.T., Yang, W., Lee, C. and Gerber, P.J. (2013). Special topics-Mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane mitigation options. *Journal of Animal Science*, 91(11), pp. 5045–5069.

163 Patra, A., Park, T., Kim, M. and Yu, Z. (2017). Rumen methanogens and mitigation of methane emission by anti-methanogenic compounds and substances. *Journal of Animal Science and Biotechnology,* 8(13).

164 Maia, M.R.G., Fonseca, A.J.M., Oliveira, H.M., Mendonça, C. and Cabrita, A.R.J. (2016). The Potential Role of Seaweeds in the Natural Manipulation of Rumen Fermentation and Methane Production, *Scientific Reports*, 6. doi:10.1038/srep32321.

Additionally – and this is what this section explores – they make much of the very different atmospheric lifetimes of methane and carbon dioxide. Methane is a short-lived gas. Prioritising measures to tackle methane's near term, high warming, but *transitory* impacts can, they argue, divert attention from the core, systemic problem: our dependence on fossil fuels, and the *permanently* damaging legacy of carbon dioxide.[165,166]

Sometimes they may argue that a different choice of metric – the Global Temperature Potential, better reflects what they see to be the less serious effects of methane and should be used instead of the prevailing Global Warming Potential (see Box 12).

Box 12: Global Warming Potential versus Global Temperature Change Potential[167]

Greenhouses gases are gases whose molecular structure affects the balance of incoming and outgoing energy in the Earth-atmosphere system, and in so doing warm the climate. This effect is measured using the so called 'radiative forcing' (RF) unit, Watts per square metre (W/m^2), which is a measure of the difference between incoming solar radiation and outgoing infrared radiation caused by the increased concentration of that gas.

Greenhouse gases differ in their RF, and the climate impact of a specific gas also depends on the time it stays in the atmosphere. Methane is removed from the atmosphere through chemical reactions (one output being CO_2) after approximately 12 years, while emitted CO_2 from fossil fuel burning or biomass destruction will stay in the atmosphere for a much longer period of time. Some of the CO_2 will be taken up by oceans and ecosystems but a large part will remain for thousands of years. In order to compare the climate impacts of these gases, an equivalising metric is needed.

The most commonly used of these is the Global Warming Potential (GWP). An alternative, which some argue should be used instead of or as well as the GWP, is the Global Temperature Change Potential (GTP). These two metrics measure slightly different things.

GWPs are a measure of the total (cumulative) radiative forcing resulting from the emission of one tonne of the gas today over a given time horizon, as compared with that of one tonne of carbon dioxide over the same time horizon. The GWP of carbon dioxide is therefore set at 1. Essentially, GWP addresses the question: what is the total amount of warming that a particular gas will contribute to the atmosphere over a period of X years in comparison with the warming caused by the same quantity of CO_2?

165 Pierrehumbert, R.T. (2014). Short-Lived Climate Pollution, *Annu. Rev. Earth Planet. Sci.*, 42, pp. 341–79.

166 Allen, M. (2015). *Short-Lived Promise? The Science and Policy of Cumulative and Short-Lived Climate Pollutants*. Oxford Martin School, University of Oxford, Oxford.

167 Information sources:
Persson, M. (2016). Livestock's carbon footprint & the importance of comparing greenhouse gases [online]. http://www.fcrn.org.uk/fcrn-blogs/umpersson/livestock%E2%80%99s-carbon-footprint-importance-comparing-greenhouse-gases (accessed 8.6.17).

Allen, M. (2015). Short-Lived Promise? The Science and Policy of Cumulative and Short-Lived Climate Pollutants. Oxford Martin School, University of Oxford, Oxford, UK.

Using the GWP metric, per tonne emitted, the warming effect of biogenic methane over 20 years are about 84 times higher than that of CO_2, and over a hundred year time-frame 28 times higher (GWPs excluding climate carbon feedbacks, based on the IPCC AR5 values – see Box 5).

Another way of measuring the impacts of different gases is the GTP. This metric compares the temperature change at a *specific* point in the future following the emission today of a tonne of a gas (methane, say), to the temperature rise at the same point in time from emitting a tonne of carbon dioxide today. Calculating the GTP requires understanding of thermal inertia – the time lag between when the emissions occur and when they cause warming, and of the Earth's climate sensitivity. This means that GTP calculations are more complicated and less certain than simple radiative forcing calculations. The question GTP tries to address is: what will the temperature change be in year X caused by this particular gas as compared with the temperature change caused by the same quantity of CO_2? As with GWP, the GTP of CO_2 is 1. In twenty years' time the temperature impact of biogenic methane is 67, and in 100 years' time 4 (GTPs excluding climate carbon feedbacks, based on the IPCC AR5 values – see Box 5). Note the difference in prepositions: GWP measures the warming effects averaged *over* 20 or 100 years - GTP measures the warming impacts *in* 20, or 100 years.

In the short term, the GTP and GWP values for methane are fairly similar; but after 100 years, there is a strong discrepancy between these values. However, both metrics give broadly similar insights: methane is more important if we are thinking about near term temperature increases, but much less so when thinking about irreversible warming.

The obvious question to ask is 'which metric is better?'

To which the response is: it depends upon what we want to do with the information.

The internationally agreed climate aim is to limit the global rise in temperatures to no more than 2°C above the preindustrial temperature average, and preferably to below 1.5°C – the latter is an aspiration whose feasibility is currently the subject of a special IPCC report.[†]

If the intention is to understand and act to avoid the short term dangers of warming – the risk that we overshoot the 1.5°C or 2°C mark even temporarily – which could lead to irreversible changes in the earth's regulatory system ('tipping points'- such as a possible complete melting of the Arctic[168]) – then the greater the need to get methane emissions down. But if we are to avoid irreversible warming – a temperature and its associated impacts to which the earth will be committed for thousands of years – then methane's impacts become less significant over a longer time-frame. But as the main body of the text emphasises, as long as the *source* of emissions continues, so will the intensity and continuity of methane's impacts. Ultimately, the choice of GTP over GWP or vice versa is less important than the advocates of a different choice of metrics suggest.

† What does seem to be clear however is that neither target will be achievable without deploying very large scale 'negative emission' technologies (including but not limited to soil carbon sequestration) or geoengineering-type approaches.

168 The Guardian (2016). Arctic ice melt could trigger uncontrollable climate change at global level [online]. https://www.theguardian.com/environment/2016/nov/25/arctic-ice-melt-trigger-uncontrollable-climate-change-global-level (accessed 8.6.17).

This sub-section takes a closer look at the debate around methane. 4.1.1 describes how methane and carbon dioxide differently contribute to the global rise in temperature in the short and long term, and discusses the relevance to the grazing livestock issue. 4.1.2 considers prehistoric methane emissions arising from wild herbivores. While this may seem a somewhat arcane question, since some in the grazing movement argue that farmed ruminants simply substitute for what would 'naturally' and historically have been emitted, the issue is worth a brief digression.

4.1.1 How do methane and carbon dioxide contribute to the global rise in temperature, and how do their long and short term effects differ?

Both atmospheric methane and carbon dioxide cause radiative forcing – that is, they absorb and re-emit some of the outgoing energy radiated from Earth's surface, causing that heat to be retained in the lower atmosphere, which then warms the earth's surface. However, beyond this generality, the effects of these two gases differ. Carbon dioxide has a weakly forcing effect – it only weakly alters the balance of incoming and outgoing energy from the atmosphere. Crucially, however, a large proportion of this carbon dioxide remains in the atmosphere for many thousands of years. Methane by contrast has a very strong forcing effect but it breaks down into CO_2 (and water) in the atmosphere after about 12 years, losing its forcing capacity (see Box 12 above). This ruminant-generated CO_2 that methane breaks down into is classed as biogenic, because it derives in the short-term from living organisms. As such, it is viewed as part of the short-term carbon cycle whereby animals respire the carbon that their food (plants) recently absorbed. This biogenic CO_2 is not considered to 'count' towards the total CO_2 emissions burden.[†]

† Natural gas, which is methane, also breaks down into CO_2 but since the source is a fossil fuel (i.e. a store of CO_2 that has kept it out of the atmosphere for millions of years) it is not classed as biogenic. As such, ultimately, it is considered to add to the accumulation of CO_2 in the atmosphere.

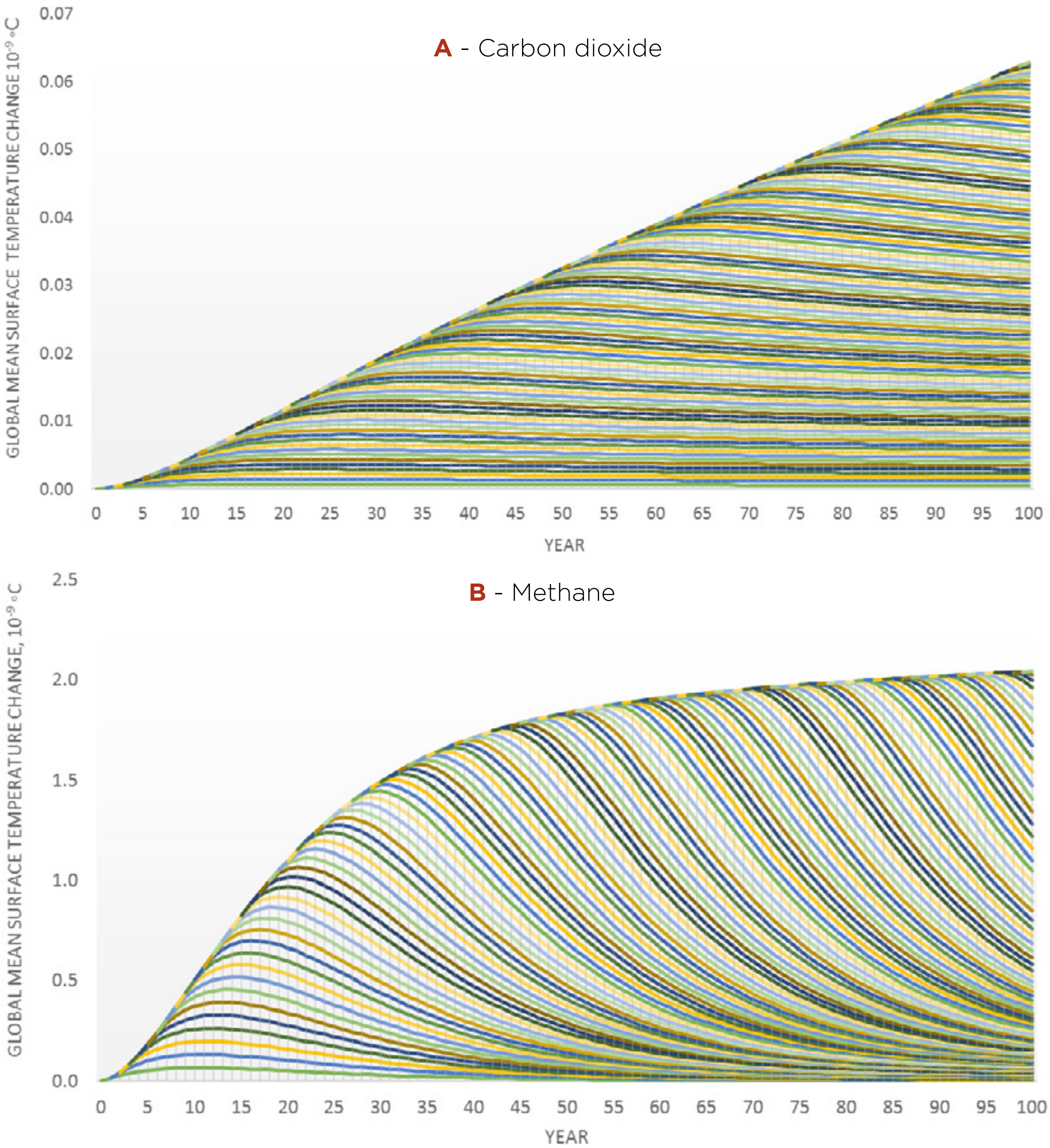
The differing implications for climate change are as follows: of one tonne of carbon dioxide emitted today into the atmosphere, approximately 40% will persist in the atmosphere and continue to exert a warming effect for hundreds and thousands of years. Any additional emissions produced – for instance a tonne of CO_2 emitted tomorrow – will *add* to the warming effects of the tonne emitted today, since most of yesterday's CO_2 still remains in the atmosphere. Thus, at a constant rate of CO_2 emissions – in the case of ruminants the source of these could be fossil-energy use for feed production, housing and so forth, or CO_2 release arising from land use change – the concentration of CO_2 in the atmosphere is not constant, but cumulative, as is the warming effect. Currently, it is also the case that the *rate* of CO_2 released into the atmosphere from these sources is increasing as the livestock (including ruminant) sector grows – a double whammy.

The situation with methane is different. A tonne of methane emitted today has a considerably stronger short term warming effect than that of a tonne of carbon dioxide, but because methane breaks down into biogenic CO_2, its overall impact over a longer time-frame progressively decreases. How these warming effects are seen to compare with those of CO_2 depends upon the choice of metric and time-frame (see Box 13).

That said, although the warming impact of a given tonne of the gas may be transitory, if the source of the gas continues to exist, so do the effects. For a steady rate of methane release – as emitted by a constant number of cattle – the warming effects of a tonne of gas emitted tomorrow, *replaces* the dwindling effects of the tonne of gases emitted today. This means that the warming effect of methane in the atmosphere persists even if it does not increase. In reality of course, the number of cattle being raised is not constant, but *increasing*. As a result, the warming contribution from methane release is not just persisting, but increasing too, albeit slowly as livestock production efficiencies improve. Note that the gains in ruminant livestock efficiencies achieved through feeding, breeding and husbandry often also mean an increase in fossil fuel dependence.

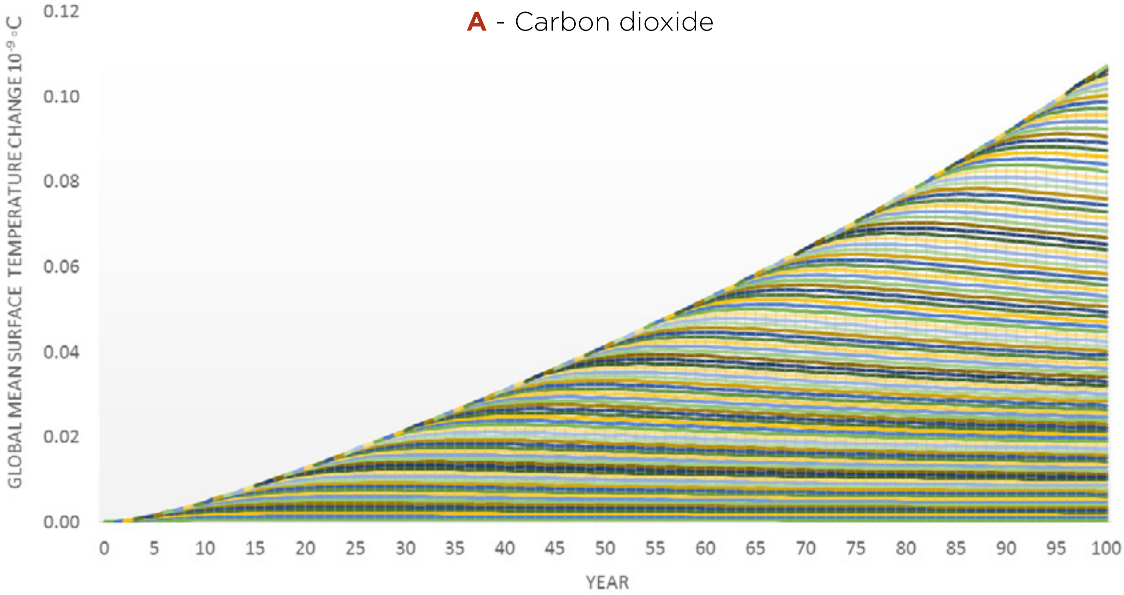
Figure 12 shows the difference in the long term warming effects of a constant rate of methane and of CO_2 emissions. A one-off, one time emission of carbon dioxide is roughly equivalent to a constant flow of emissions of methane at the rate of its decay. Figure 13 makes the same point but also shows that the rate both of CO_2 and methane emissions is not steady but increasing.

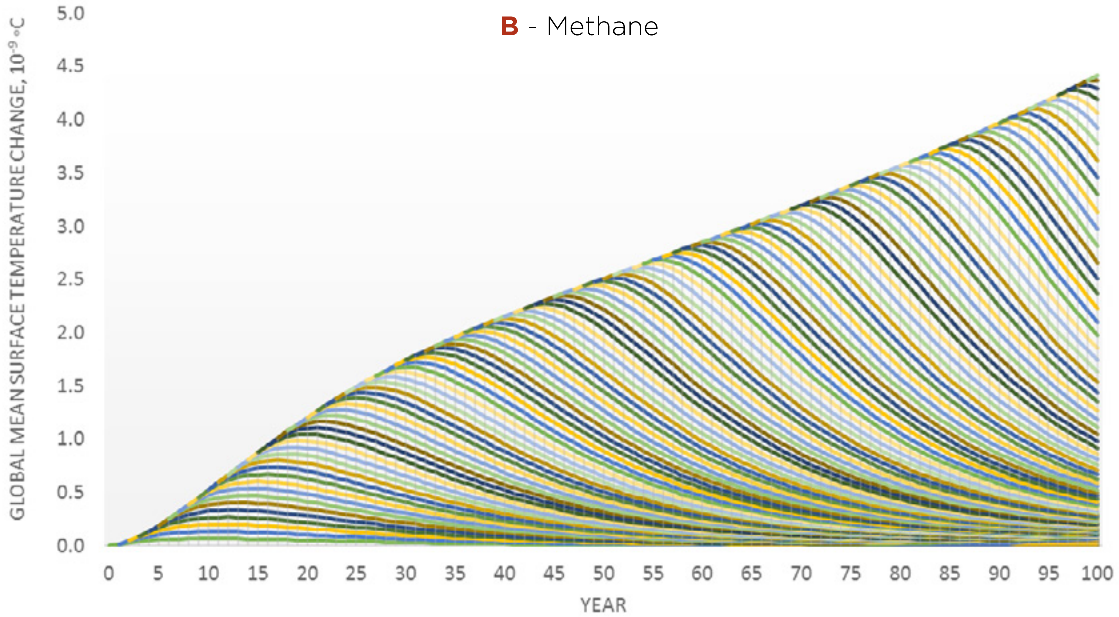
Figure 12: Difference in the long term warming effects of a constant rate of methane and of CO_2 emissions.



*Global mean surface temperature change related to a constant emission rate of 1 t CO_2/year (**A**) and 1 t CH_4/year (**B**). Each line represents a pulse of emission, adding up to the CO_2 or CH_4 emitted in previous years, up to the moment it is broken down and removed from the atmosphere. Note the difference in scale on the y-axis between the two graphs.*

Figure 13: Difference in the long term warming effects of an increasing rate of methane and of CO_2 emissions





*Global mean surface temperature change related an increasing emission rate of CO_2 (**A**) and CH_4 (**B**) of 1% a year, starting at an emission of 1 t in the first year. Each line represents a pulse of emission, adding to the CO_2 or CH_4 emitted in previous years, up to the moment it is broken down and removed from the atmosphere. Note the difference in scale on the y-axis between the two graphs.*

NB For both Figures 12 and 13: *The climate impacts of CH_4 and CO_2 were modelled over time using the same expressions for relating emissions of GHGs to changes in atmospheric concentrations and resulting radiative forcing as the IPCC uses for calculating GWPs and GTPs (Myhre et al. 2013[169]; Persson et al. 2015[170]). The model simulates the radiative forcing trajectory and corresponding global mean surface temperature change of a certain amount of CO_2 or CH_4. It uses the same set of assumptions regarding the radiative efficiency and atmospheric lifetimes of the GHGs as used by IPCC AR5.*

How should these differences influence judgements about what to do?

Action to reduce CO_2 emissions is – it goes without saying – essential.[171] Since a large portion of every emission of CO_2 is permanent (as far as human time scales are concerned), each tonne emitted into the atmosphere today commits us to a level of warming not just now but *in perpetuity*.

Two points follow of relevance to methane. First: if action is taken to reduce methane emissions *in the absence of concerted* efforts to address CO_2, then this delivers a false benefit given that an emission of methane is temporary and an emission of CO_2 is relatively permanent. The relative permanence of CO_2 and the cumulative effects of ongoing CO_2 release mean that we are 'committed' to warming in the future, even if all methane sources were eliminated today. In this sense, advocates of grazing livestock are right to warn against being distracted from tackling the deep systemic problems of fossil fuel use.

By contrast, if ruminant livestock production were to stop tomorrow, within a few decades the legacy of the methane emissions would disappear also. However – and this is point two – grazing advocates *are not* advocating the cessation of ruminant livestock rearing. Quite the contrary, their argument is that since methane's impact are transitory, the generation of methane by livestock is not a problem. This is incorrect: as long as ruminant livestock production continues, so do methane emissions. If livestock are still reared in fifty or a hundred years' time, they will still be emitting methane,[†] the methane they produce then will still be contributing to warming, and methane's strong warming effects mean that we more rapidly reach the higher temperatures that will have such devastating effects on agriculture, wildlife's ability to adapt, heat stress in humans and animals, and more.

[†] Unless we develop effective methane inhibitors. This is not the place to discuss their potential and if one were to factor in assumptions about their existence one might just as well assume a phase out of fossil fuel use. Both are important – both are as yet beyond our reach.

[169] Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang. (2013). *Anthropogenic and Natural Radiative Forcing*. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[170] Persson, U.M., Johansson, D.J.A., Cederberg, C., Hedenus, F. and Bryngelsson, D. (2015): Climate metrics and the carbon footprint of livestock products: Where's the beef? *Environmental Research Letters,* 10(3).

Myhre, G., Shindell, D., Bréon, F.-M., Collins, W., Fuglestvedt, J., J. Huang, D.K., Lamarque, J.-F., Lee, D., Mendoza, B., Nakajima, T., Robock, A., Stephens, G., Takemura, T., H. Zhang. (2013). *Anthropogenic and Natural Radiative Forcing*, In: Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung.

A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[171] Allen, M.R., Frame, D.J., Huntingford, C., Jones, C.D., Lowe, J.A., Meinshausen, M. and Meinshauswen, N. (2009). Warming caused by cumulative carbon emissions towards the trillionth tonne. *Nature,* 458, pp. 1163–1166.

It is also the case that an either-or separation of the methane from the CO_2 problem in ruminant systems is misleading. On the positive side, measures to increase soil carbon by planting particular forage crops can be more digestible to ruminants and so reduce their enteric methane emissions – a double mitigation benefit. More negatively, the idea, often propounded by advocates of grazing systems, that these are less fossil fuel dependent than more intensive systems, is at best exaggerated and at worst untrue. Most extensive grazing systems are important sources of fossil fuel derived CO_2.[172] This CO_2 can be released through the use of fossil fuels to produce feed, agro-chemicals and fencing, and to house and water the animals. Very few ruminants systems receive no inputs whatsoever of that nature.

And there is also a second connection with CO_2 release. Although a few very extensive pastoral systems use few fossil fuel inputs, CO_2 may be released following livestock-induced deforestation or land degradation. While well-managed systems that are not implicated in deforestation certainly exist, if one were to push this line of thinking further to argue – which advocates do – that all current beef eaters should consume beef produced only in this ultra-extensive way without also cutting back drastically on intakes, *and* that beef should be consumed in preference to pork and poultry, *and* if one were to multiply this up by 7, 8, 9, 10 billion people, the increased requirement for beef production would entail large scale forest clearances and consequent CO_2 release: a release whose effects are, as discussed, permanent. Advocates of high management-intensity intermittent or holistic grazing argue that these systems enable much larger numbers of animals to be reared on a given land area, and so the land demand is not as great as the evidence suggests. Chapter 5 discusses these arguments in more detail.

4.1.2 Methane and wild herbivores in prehistoric times

The short atmospheric lifetime of methane is one argument grazing system advocates use to argue that methane does not really matter. The second argument is that, at some level, methane is 'natural' since in prehistoric times, as huge herds of wild herbivores roamed the earth. Being ruminants, these animals also produced large quantities of methane. Farmed animals are simply substituting, methane-wise, for what went on before.[173,174,175]

And indeed, one study[176] which estimated methane emissions from wild herbivores at various periods in history and pre-history found that during the Late Pleistocene (12–13,000 years ago) the emissions these animals produced were virtually equivalent to those of farmed animals today (Figure 14). Megafauna numbers then dwindled, possibly because of human hunting and climate change. The methane count accordingly

172 Röös, E., Sundberg, C., Tidåker, P., Strid, I. and Hansson, P.-A. (2013). Can carbon footprint serve as an indicator of the environmental impact of meat production? *Ecological Indicators,* 24, pp. 573–581.

173 Niman, N. (2014). *Defending Beef: The Case for Sustainable Meat Production*. Chelsea Green Publishing, USA.

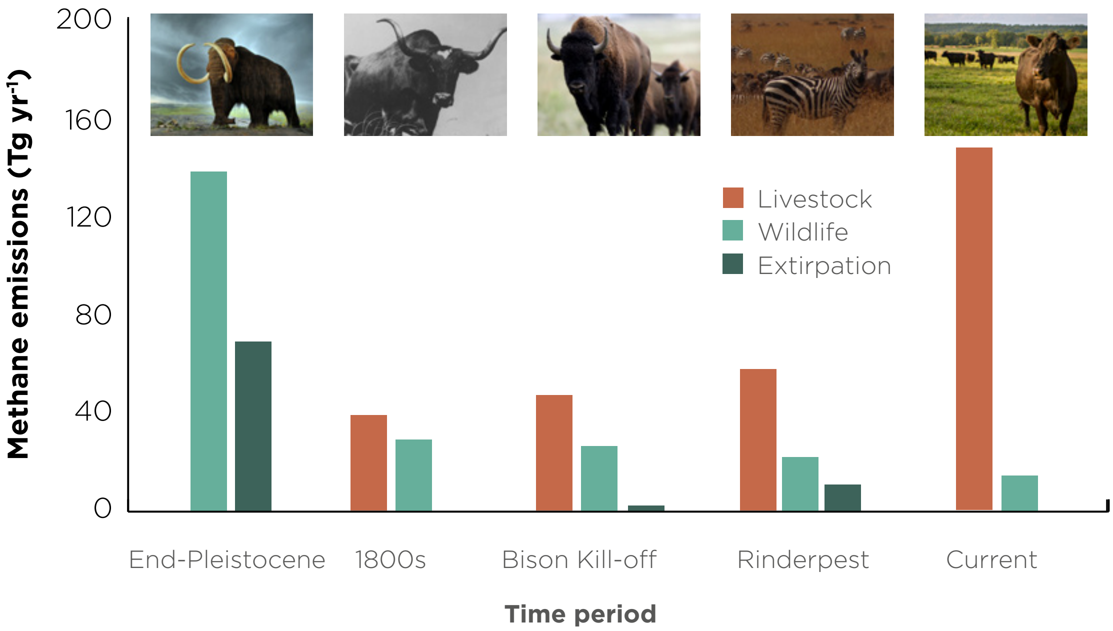
174 Weston A. Price Foundation (2008). An Inconvenient Cow [online]. https://www.westonaprice.org/health-topics/vegetarianism-and-plant-foods/an-inconvenient-cow/ (accessed 8.6.17).

175 Shaping Tomorrow's World (2012). Cattle and methane: More complicated than first meets the (rib) eye [online]. http://www.shapingtomorrowsworld.org/wahlquistmethane.html (accessed 8.6.17).

176 Smith, F.A., Hammond, J.I., Balka, M.A., Elliott, S.M., Lyons, K., Pardia, M.I., Tomé, C.P., Wagner, P.J. and Westover, M.L. (2016). Megafauna and ecosystem function from the Pleistocene to the Anthropocene, *Proc. Natl. Acad. Sci.* USA 113(4) 838–846.

plummeted, a fall which may have contributed to the drop in global temperatures over that period. Further, smaller dips in wildlife-generated methane emissions occurred during the nineteenth century, induced by the African Rinderpest outbreak, and later by the hunting-induced extirpation of bison on the North American Plains.

Figure 14: Methane emissions from livestock, wildlife and extirpation from the End-Pleistocene to today. From Smith *et al.* (2016)[177]



Malhi *et al.* (2016)[178] additionally suggest that these pre-historic megafauna might have had complex effects on the climate in other ways too, such as by altering the albedo effect. As the megafauna died out, the forests expanded, causing a carbon uptake that cooled the climate. On the other hand, in northern latitudes, the replacement of a pale reflective surface (grassland) by darker encroaching conifers caused the earth to absorb more of the sun's heat. The net impacts are unclear – and, as the authors point out, a full accounting would need 'to include enteric methane emissions, soil greenhouse gas emissions related to changes in hydrology and temperature, and changes in surface albedo and evapotranspiration related to vegetation structure'.

What these studies show very clearly is that animals have always had an impact on global greenhouse gas emissions, and thus on the global climate. Wildlife-generated methane emissions in the Late Pleistocene were comparable to what they are today and they may also have affected the carbon cycle through their effects on forest cover and on albedo.

[177] Smith, F.A., Hammond, J.I., Balk, M.A., Elliott, S.M., Lyons, S.K., Pardi, M.I., Tomé, C.P., Wagner, P.J. and Westover, M.L. (2016). Exploring the influence of ancient and historic megaherbivore extirpations on the global methane budget. *Proc Natl Acad Sci*., 113(4), pp. 874–879.

[178] Malhi, Y., Doughy, C.E., Galetti, M., Smith, F.A., Svenning, J.-C. and Terborough, J.W. (2016). Megafauna and ecosystem function from the Pleistocene to the Anthropocene, *PNAS*, 113(4), pp. 838-846.

On the other hand, at a very practical level this information is meaningless. This ecological baseline is so far in the past that, while interesting, its relevance to the challenges we face today is negligible. Everything was utterly different. To derive a conclusion from this and similar such studies that the levels of methane generated by farm animals today are somehow 'okay', is misleading for two reasons. First, global methane emissions are today adding heat to what is already a dangerously warming climate, a warming largely but not exclusively caused by the growth in fossil fuel use and by (partly livestock-induced) forest clearance. The context has changed, and the importance of animal related methane emissions has increased.

And second, there is a vast difference in the conservation and ecological value between the rich species mix of wild herbivores that roamed the grasslands of the past, and the uniformity of farmed animals today. To express it in quasi-economic terms, the ecological 'value-for-methane' of wild herbivores, such as are still found, albeit in decimated numbers, vastly exceeds that of our impoverished genetic and species mix of cattle, sheep and goats. The same applies to the wetlands and termite colonies of today – these also produce methane but we 'budget' for their impacts since, as part of the natural world, their preservation constitutes one of the reasons why we might want to address climate change in the first place.

If the goal is to conserve what is left of biodiversity on earth, and as such to safeguard and expand existing populations of wild herbivores because of their intrinsic value as well as the more instrumental ecosystem services they provide – and recognising that they also constitute a source of methane emissions – then the need to reduce domestic livestock populations is all the greater.

It is also worth noting that were action taken to 'rewild' grasslands lands currently used for livestock rearing, any increases in wild animal numbers we managed to achieve would be very slow. We would not suddenly substitute one methane problem with another – and the success of any such programme would likely only be possible in the context of radically different policies and ultimately a radically different world order. It is inconceivable that attention would be paid to rewilding, without us also taking action to address other fundamental environmental problems, most notably our fossil fuel use and our human population numbers. In other words, a world repopulated with herbivores would also be one where the dependence on fossil fuels would be cut. The world – both practically and politically – would be hugely different from what it is today.

4.2 On the importance of nitrous oxide

Nitrous oxide enjoys a doubly high-impact status as a greenhouse gas: although it is emitted in small quantities, it is both extremely potent (around 265 times more so than CO_2) and relatively long lived.

And yet it is interesting to note that within the grazing advocacy movement, ruminants' contribution to N_2O emissions tends to receive little attention. On the other hand, much is generally made of the fertilising effects of their nitrogen-rich dung.

This section takes a closer look at nitrogen, its incarnations both as a greenhouse gas and a source of plant nutrients and the relationship of both to grazing ruminants. The first part provides a brief explanation of livestock's role in the nitrogen cycling process on grazing lands and specifically the contribution that manure makes to fertilising soils (4.2.1). The second part looks at how nitrogen-carbon cycle interactions affect the success of ruminant-related efforts to reduce GHGs (4.2.2).

4.2.1 Grazing ruminants, the nitrogen cycle and the fertilising effects of manure

Nitrogen is essential to the workings of the terrestrial carbon cycle. All living creatures require nitrogen, since it is a building block of the amino acids that ultimately make up proteins, including enzymes. The use of nitrogen begins with plants. Plants harness energy from the sun but nitrogen (and other nutrients) also need to be present and available in soils for them to take up and use to make DNA, amino acids and ultimately proteins.

When animals eat these plants, the plant proteins are broken back down into amino acids. These are rebuilt into animal proteins, and in this way the nitrogen becomes incorporated into muscle, milk and, in the case of ruminants, their ruminal bacteria. Moving further up the food chain, humans then eat the animals that have eaten the plants, although of course we also more directly eat plants too.

Nitrogen is bountifully present in the atmosphere, but is very stably bonded to itself and highly inert. As such, it is not readily converted into a non-gaseous form and transferred to soils. Nevertheless some natural processes enable this to happen which farmers may draw upon: legumes (via their bacteria), blue green algae and free-living nitrogen-fixing bacteria in the soil have the capacity to take nitrogen out of the atmosphere, as does the occasional bonus lightning strike. The other (artificial) option is to use the highly energy intensive Haber-Bosch process to convert the N_2 to ammonia.

The problem with nitrogen is that, once converted, it becomes a highly capricious substance, capable of causing multiple different environmental problems depending upon which chemical pathway it pursues. One of these pathways leads to nitrous oxide with its attendant forcing effects.

The other point to note is that living organisms are 'inefficient' in their use of nitrogen, which makes for a leaky nitrogen cycle. Plants take up some of the available nitrogen; the rest remains in the soil. This means that later generations of plants can utilise it but also that – depending on the specifics of climate, soils and temperature – the nitrogen may be transformed into N_2O, or else into forms that cause soil and water pollution.

In a natural system, when animals eat the plants, there are further leakages. Some of the plant nitrogen that the animals eat is retained to support their growth (the building of muscles and so forth), but much[179] is returned to the soil (or to waterways) in the form of dung and urine. These depositions offer a mixture of positives and negatives. They have the virtue of delivering nutrients in a form that is readily available to plants and in that respect they aid plant growth. But since plant nitrogen uptake is only

[179] Gerber, P.J., Uwizeye, A., Schulte, R.P.O., Opio, C.I. and de Boer, I.J.M. (2014). Nutrient use efficiency: a valuable approach to benchmark the sustainability of nutrient use in global livestock production? *Current Opinion in Environmental Sustainability*, 9(10), pp. 122-130.

partial, the rest remains in the soil where it may be converted into nitrous oxide or be lost through other pathways. Inevitably, the urine and dung is not perfectly distributed but patchy, producing nutrient surpluses in some parts of the field (often close to water points) and deficiencies in another. It is critical to note, moreover, that the nitrogen that the dung and urine contains is not *new* nitrogen: it originates from the plants that the animals consume.

In a natural grazing system, the nitrogen cycle is fairly localised. When the plants die, the nitrogen in them is returned to the soil. If animals eat them first, the animals will return some of the nitrogen to the soil while they are alive in the form of urine and dung, and the remainder when they die and rot away. The animals may be eaten by a predator, and it by another predator, and because animals move about so too will their nitrogen deposits; but ultimately, all the animals die and most of the nitrogen ends up back on the soil quite close to its original starting point. Of course, some nitrogen is inevitably lost to water and air through various chemical pathways, but free-living bacteria and the leguminous plants naturally present in the species mix keep the system topped up, so to speak. That said, the less nitrogen present and the fewer the leguminous plants, the slower the vegetation growth, and the fewer animals the system can support. On the plus side, N_2O emissions from grazing animals in a natural system will be low, since nitrogen availability is itself low.

In a farm grazing system however, things are different for two main reasons. First, farmers will also want to make a living, which means that the stocking rate will need to be higher than what the land can naturally support. Second, and linked to this, unlike in a natural system, much of the nitrogen the animals consume leaves the system in form of meat, milk or eggs. This means that the lost nitrogen needs to be replenished by other means.

Where land is very abundant, the stocking rate in grazing systems can be low enough to match the natural rate of nitrogen restoration (via legume fixing); traditionally livestock were let out to graze and then brought down into enclosures for the night, where their manure was stored and used to fertilise crops. The crops in effect made use of the embedded nitrogen from 'borrowed' grazing lands. But this approach is possible today only in pockets of the world. In most regions, there is simply not enough land to support the number of grazing animals needed to produce manure in quantities sufficient to fertilise both our crop lands and the pastures the animals graze on – unless one chooses to clear forests.

The nitrogen in the system therefore needs to be 'topped up'. One option is to use synthetic fertilisers. Haber-Bosch has fed the world for the last century or so but it has also made available an abundant and cheap source of rope with which to hang ourselves, environmentally speaking. Some of the problems arising from the use of synthetic fertilisers were discussed in Section 3.4.

The alternative is to plant legumes on pastures. This too was discussed in Section 3.4. Legume planting offers a solution in some areas – but its potential is geographically limited and it is also worth noting that legume sowing will also undermine the diversity of the natural grassland species mix (to be discussed more in a separate report).

A third option is to supplement the grazing animals' feed. In this case, the feed contains the nitrogen of distant lands – it is an import to the system, causing a cost elsewhere. It is worth noting that this is what some holistic-type grazing systems which claim to achieve very high stocking rates (see Section 5.4 below) actually do. The ruminants themselves receive no supplements but pigs and poultry are also allowed to forage on the grass. These animals have been fed grains[180,181] and so the nitrogen in their manure, which acts as a soil fertiliser, is an import to the system.

The fourth option is to 'borrow land' by incorporating grazing animals into the cropping system. In an organic mixed crop-livestock system, leguminous crops can be grown as part of the rotation to provide forage for the animals and to fix nitrogen for the next generation of crops and animal manure can also act as soil fertiliser. However as noted, manure adds no new nitrogen to the system and today it contributes to only 12% of all cropland nitrogen inputs.[182] Moreover, viewed over time (the three, four or five years of the rotation) more land is necessarily required per given volume of food output (both crops and animal products) than in a system where soils are fertilised using synthetic nitrogen, and there is no ley period. In a land-limited world, this counts as a cost.

All of these inputs (land, legumes, fertilisers), by bringing in new nitrogen, also increase the risk of N_2O fluxes, leaching and other forms of damaging nitrogen loss.[183,184]

Returning to manure: what this explanation very clearly shows is that there is no such thing as a free lunch. Manure seems to have acquired a quasi-magical status within the grazing – and indeed the organic – community. There is a sense that via their manure ruminants create something out of nothing, that it not only fertilises the soil, stimulating plant growth and supplying the animals themselves with their sustenance, but in so doing, it fosters the process of soil carbon sequestration. But there is of course no magic. Animals do not bring new nitrogen into the system – they just move it about, and if we continue to eat them and their products, there is ultimately a net loss of nitrogen from the farming system. Ultimately, the nitrogen contained in the manure and urine *is less than what the land originally started with*.

4.2.2 Nitrogen-carbon interactions and the net mitigation question

What the explanation above makes clear is that first, to maintain the production system, some input of nitrogen is needed, and second, when it comes to livestock and their role in fertilising the soil someone or something always has to foot the bill.

This observation also has implications here for soil carbon sequestration. Plants sequester carbon if they grow well, but they only grow well if there is sufficient

180 Polyface Farms (2017). Pastured Broilers [online]. http://www.polyfacefarms.com/pastured-broilers/ (accessed 8.6.14).

181 Polyface (2017). Polyface, the farm of many faces [online]. http://www.polyfacefarms.com/2011/07/25/pigaerator-pork/ (accessed 8.6.17).

182 Bouwman, L., Klein Goldewijk, K., Van Der Hoek, K.W., Beusen, A.H.W., Van Vuuren, D.P., Willems, J., Rufino, M.C. and Stehfest, E. (2013). Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900–2050 period. *PNAS*, 110(52), pp. 20882–20887.

183 Liu, J., You, L., Amini, M., Obersteiner, M., Herrero, M. and Zehnderf, A.J.B (2010). A high-resolution assessment on global nitrogen flows in cropland. *PNAS*, 107(17), pp. 8035–8040.

184 Bouwman, L., Klein Goldewijk, K., Van Der Hoek K W, Beusen, A.H.W., Van Vuuren, D.P., Willems, J., Rufino, M.C. and Stehfest, E. (2013). Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900–2050 period. *PNAS*, 110(52), pp. 20882–20887.

nitrogen. All the measures identified above generate N_2O emissions. At times and as Section 3.4 discussed, the sequestration gains will outweigh the warming effects of N_2O – but at times it will not. The trade-offs will be context-specific.

Of course in many contexts the relative practical constraints will preclude the use of nutrient amendments to soils. Since nitrogen is limited, so is plant growth, which in turn limits soils's carbon sequestering capacities. Grasslands in tropical regions are of course also subject to drought, which reverse any wet-season soil carbon gains. These are some of the reasons why ambitious soil carbon targets, such as that of the 4 per 1000 initiative, are unlikely to be achieved.[185]

[185] Van Groenigen, J.W., van Kessel, C., Hungate, B.A., Oenema, O., Powlson, D.S. and van Groenigen, K.J. (2017). Sequestering Soil Organic Carbon: A Nitrogen Dilemma. *Environ. Sci. Technol.*, 51, pp. 4738–4739.

5. Grazing systems and their role in land use and land use change

Key points

- Humans have transformed over 50% of the earth's surface, largely for agriculture.
- Croplands take up 12% of the earth's surface; grazing lands about 26%.
- Land clearance to create pasture for ruminants has historically been a major cause of deforestation; deforestation-induced land use change accounts for 9-34% of emissions from livestock.
- Land use trends vary regionally.
- In Latin America, cattle pasture is the main user of deforested land. There are debates however as to the underlying factors determining this use and therefore the relative importance of cattle production versus insecure land tenure, and of the role that crop expansions play in indirectly driving pasture expansion in the region.
- In Europe and North America both land abandonment and crop expansion are co-occurring.
- The loss of natural grasslands is driven by pasture intensification as much as by cropping.
- There is large uncertainty in future projections of land use. Future changes will depend on, among other things: trends in crop and livestock productivity; trajectories of food demand; and the existence or otherwise of effective regulations limiting land use change. At a larger scale, global forces, from war and migration to social movements, as well as technological 'wild cards' will also shape future land use.
- In a scenario where livestock are exclusively reared on grasslands, per capita daily supply of animal protein could be between 7–18 g.
- The additional use of non-food products as feed (food waste and crop by-products) to feed other livestock species too could increase the supply to about 11-32 g of animal protein/person/day, with a mean of 21 g.
- The global forecast daily per capita average animal protein supply in 2050 (from all livestock types) is 31 g although this figure masks massive differences between countries and within country populations and includes losses and waste.
- Current average supply of animal protein in high income regions is about 50-60 g protein/person/day.

- Efforts to meet high demand for grassfed beef and milk by increasing stocking rates would lead to correspondingly higher methane and nitrous oxide emissions; increases achieved through pasture expansion would additionally generate deforestation-induced CO_2 emissions.
- Moderating high levels of animal product consumption would free up land for other uses including cropping, forest regrowth and rewilding, and bioenergy production and would also increase the option space for less intensive production systems.

Chapter 3 considered whether and how grazing livestock might help carbon accumulate in soils, in view of the many claims that have been made about their potential. But notwithstanding any sequestration potential they may afford, ruminants indisputably have a very long track record in causing carbon to be *lost* from the terrestrial system, since they have historically been a major cause of forest loss.

The question now is whether this relationship between deforestation and grazing ruminant production still continues; or whether the drive towards intensification and the rapid ascendancy of the chicken are creating some very different dynamics of land use.

This chapter considers past, present and possible future trends in land use and the changing influence of livestock – particularly grazing ruminants – on these trends. What have grazing livestock done so far to the land, for good and for bad? How and why are things changing now? It concludes with some alternative configurations of land use, both those involving grazing systems and those that do not, and considers what these might mean for carbon emissions, carbon removals and the other greenhouse gases.

It begins, however, in the past.

5.1 Past changes and baseline ecological states

As of today, humans have transformed over 50% of the earth's terrestrial surface, and since our influence can even be discerned on so called 'wild' land, in practice there is now virtually nowhere on the planet untouched by our presence.[186] Most of this transformation has mostly been undertaken to feed ourselves: croplands today take up 12% of the land area, while grazing lands are double that at 22–26%.[187,188,189] While some of these grazing lands are natural, many are the products of deforestation. As

[186] Hooke, R.LeB., Martín-Duque, J.F. and Pedraza, J. (2012). Land transformation by humans: A review. *GSA Today*, 22(12), doi: 10.1130/GSAT151A.1.

[187] Ramankutty, N., Evan, A.T., Monfreda, C. and Foley, J.A. (2008), Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000, *Global Biogeochem. Cycles*, 22, GB1003, doi:10.1029/2007GB002952.

[188] FAO (2010). The State of Food and Agriculture 2009: Livestock in the Balance. Food and Agriculture Organisation, Rome.

[189] Hooke, R.LeB., Martín-Duque, J.F. and Pedraza, J. (2012). Land transformation by humans: A review. *GSA Today*, 22(12), doi: 10.1130/GSAT151A.1.

ruminants utilise both grazing and cropland, their impact has literally been earth-changing.

While the sheer extent of our planetary impact is indisputable, the recency of the changes wrought are a matter of some debate. Some argue that most of these changes began just a few centuries ago, spurred on by the connected forces of industrialisation and population growth. Others argue for our more long-standing influence on the natural world, dating our impact as far back as the beginning of the Holocene 11,000–12,000 years ago, when the ice started to retreat.[190] These two narratives of change are supported by two opposing historical land use reconstruction models. One (HYDE) supports the first narrative, finding our impacts to be for the most part a consequence of the last few hundred years, except in Europe, the Mediterranean and in small pockets of East Asia, South Asia and West Africa. The other (KK10) tells a radically different story of ancient use and lately, signs of land abandonment, as we become more productive in our use of land. Annex 2 provides a fuller discussion.

How do these models and these debates relate to the question of grazing livestock's impacts today, and potentially in the future? Surely, whatever the 'true' starting point of transformation, what both models clearly show is the severity and depth of our planetary alteration today, and as such the challenge now is to figure out ways of feeding ourselves without causing further damage.

This is all true, but ideas about the past have a habit of influencing discussions about the future: the question of what a future desirable land use state looks like tends to be shaped by implicit if not always explicit visions of a preferable, lost, past ecological state, from which today's landscape departs.[191] This is particularly so when it comes to biodiversity (discussed in another report), and it manifested itself too in the discussion about prehistoric methane emissions (Section 4.1 above) – but it also applies to the greenhouse gas question, since grasslands, croplands and forests offer different possibilities for above and below ground carbon storage and sequestration, and their role has changed over time because of human activity, aided by fluctuations in climate. For example and to oversimplify: it is possible to argue that since much grazing land was historically forest, the 'best' thing to do would be to leave as much as possible to revert to its 'natural' pre-human state. This implies that human food production should be as intensive as possible. This in turn suggests that a shift towards plant-based diets would be desirable, since a whole level in the food chain is removed, thereby improving food conversion efficiencies and reducing land requirements further. Others argue that many of the grazing lands in existence today were created hundreds if not thousands of years ago -that is, that we and our animals have been important co-shapers of landscapes – and that some are in any case natural. Grasslands today embody a considerable store of carbon and maintaining them with grazing animals helps ward off the destructive influence of the plough.

[190] Ellis, E.C., Kaplan, J.O., Fuller, D.Q., Vavrus, S, Klein Goldewijk K and Verburg P H (2013). Used planet: A global history, PNAS, 110(20), pp. 7978-7985.

[191] Alagona P S., Sandlos, J. and Wiersma, Y.F. (2012). Past Imperfect: Using Historical Ecology and Baseline Data for Conservation and Restoration Projects in North America, *Environmental Philosophy,* 9 (1), pp. 49–70.

5.2 Deforestation and land use change: recent and current trends

Whatever one's views about the *future* use of existing grazing lands, there is more or less unanimous agreement that the deforestation still taking place today should stop. While in many regions forest cover is stable, this general account of the situation hides essential detail. In the tropics, deforestation is still increasing,[192] and some gains in forest cover come from the expansion of plantations; there is a world of ecological difference between the old forests, which are being lost, and new planted ones.

Importantly, land that is not forest is also still being converted; natural grasslands are particularly at risk. The physical extent of natural grasslands has diminished as has its quality; its biodiversity status has become impoverished as a result of intensification or degradation.[193,194,195] As for grazing land – that is, lands used to rear domesticated animals be they natural or not – declines in some parts of the world (Europe, China, the Pacific region) have been countered by increases elsewhere, including Latin America, North America and parts of Africa.[196] Overall, while the area devoted to cropping continues to increase, the grazing land area has fallen slightly from its peak at the turn of the new millennium.[197] Land quality is also an important part of the story of change – an estimated 20–35% of grazing lands globally suffer from some form of degradation.[198]

Crucially, the fluctuating fortunes of different land types play out differently in different regions, generated by and engendering different kinds of challenges and opportunities. The situations in three regions are briefly discussed here.

5.2.1 South America

Everyone knows about Amazonian deforestation. It is the go-to, most obvious depiction of land use change, and one where the livestock connection is firmly entrenched in people's minds. The impacts for biodiversity and for the climate are well

[192] FAO (2016). *State of the World's Forests: Forests and agriculture: land-use challenges and opportunities*. Food and Agriculture Organisation, Rome.

[193] White, R., Murray, S. and Rohweder. (2000). *Pilot Analysis of Global Ecosystems: Grassland Ecosystems*. World Resources Institute, Washington D.C.

[194] Bond, W.J. (2016). Ancient grasslands at risk: Highly biodiverse tropical grasslands are at risk from forest-planting efforts. *Science*, 351(6269).

[195] Newbold, T., Hudson, L.N., Arnell, A.P., Contu, S., De Palma, A., Ferrier, S., Hill, S.L.L., Hospkins, A.J., Lysenko, I., Phillips, H.R.P., Buron, V.J., Chng, C.W.T., Emerson, S., Gao, D., Pask-Hale, G., Hutton, J., Jung, M., Sancheq-Ortiz, K., Simmons, B.I., Whitmee, S., Zhang, H., Scharlemann, J.P.W. and Purvis, A. (2016). Has land use pushed terrestrial biodiversity beyond the planetary boundary? A global assessment. *Science*, 353(6296), pp. 288-291.

[196] Klein Goldewijk, K., Beusen, A., Doelman, J. and Stehfest, E. (2016). New anthropogenic land use estimates for the Holocene; HYDE 3.2. *Earth Syst. Sci. Data Discuss.*, doi:10.5194/essd-2016-58.

[197] Klein Goldewijk, K., Beusen, A., Doelman, J. and Stehfest, E. (2016). New anthropogenic land use estimates for the Holocene; HYDE 3.2. *Earth Syst. Sci. Data Discuss.*, doi:10.5194/essd-2016-58.

[198] Godde, C., Garnett, T., Thornton, P., Ash, A. and Herrero, M. (2017). Grazing systems expansion and intensification: drivers, dynamics, and trade-offs. *Global Food Security*. (under review).

known: the mildly cud-chewing cow has become the poster child of rapacious agri-biz.[199,200,201,202]

While the expansion of protected areas, improved government enforcement on private lands, and market initiatives have slowed the rate of forest loss considerably over the last decade or so[203,204,205] (the economic downturn also helped)[206] the signs are that very recently rates have started to creep up again.[207] Additionally the locus of land use change has shifted and so the damage continues, albeit in a different incarnation. With all eyes on the trees, the agricultural sector has moved onto the less charismatic grass. The Cerrado – despite its vast carbon stores, unique biodiversity and the fact that much of the biome actually includes forests and shrubs as well as grassland[208] – has attracted the intense interest of both the arable and livestock sectors.

The obvious questions to ask are: Why? Who or what is to blame? What are the drivers of changing land use?

These are difficult questions to answer since the social and economic drivers of deforestation are complex, dynamic and highly context-specific. This opens up the discussion for much disagreement, some of which reflects strong ideological positions.

While few dispute the fact that cattle ranching in the Amazon has had devastating consequences for forest and biodiversity loss (Figure 15), the question then arises: what drives cattle ranching? One explanation is insecure land tenure, which is a

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199 McAlpine, C.A., Etter, A., Fearnside, P.M., Seabrook, L. and Laurance, W.F. (2009) Increasing world consumption of beef as a driver of regional and global change: A call for policy action based on evidence from Queensland (Australia), Colombia and Brazil, *Global Environmental Change*, 19, pp. 21-33.

200 Ripple, W.J., Smith, P., Haberl, H., Montzka, S.A., McAlpine, C. and Boucher, D.H. (2014). Ruminants, climate change and climate policy. *Nature Climate Change*, 4, pp. 1-5.

201 De Sy, V., Herold, M., Achard, F., Beuchle, R., Clkevers, J.G.P., Lindquist, E. and Verchot, L. (2015). Land use patterns and related carbon losses following deforestation in South America. *Environ. Res. Lett.*, 10(12). doi:10.1088.

202 Greenpeace (2009). How cattle ranches are chewing up the Amazon rainforest [online]. http://www.greenpeace.org.uk/blog/forests/how-cattle-ranching-chewing-amazon-rainforest-20090129 (accessed 8.6.17).

203 Assunção, J., Gandour, C. and Rocha, R. (2015). Deforestation slowdown in the Brazilian Amazon: prices or policies? *Environ. Dev. Econ.*, 20, pp. 697-722. doi:10.1017/S1355770X15000078.

204 Börner, J., Kis-Katos, K., Hargrave, J. and König, K. (2015). Post-Crackdown Effectiveness of Field-Based Forest Law Enforcement in the Brazilian Amazon. *PLoS ONE,* 10. doi:10.1371/journal.pone.0121544.

205 Soares-Filho, B., Moutinho, P., Nepstad, D., Anderson, A., Rodrigues, H., Garcia, R., Dietzsch, L., Merry, F., Bowman, M., Hissa, L., Silvestrini, R. and Maretti, C. (2010). Role of Brazilian Amazon protected areas in climate change mitigation. *PNAS*, 107, pp. 10821-10826. doi:10.1073/pnas.0913048107.

206 Graesser, J., Aide, T.M., Grau, H.R. and Ramankutty, N. (2015). Cropland/pastureland dynamics and the slowdown of deforestation in Latin America. *Environ. Res. Lett.*, 10(3). Doi :10.1088/1748-9326/10/3/034017.

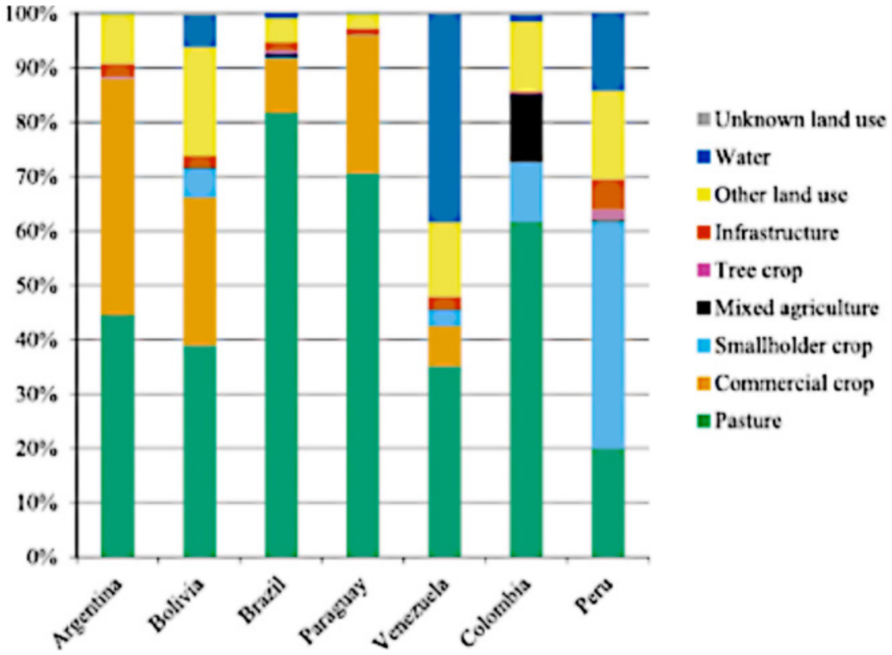
207 Mongabay (2016). Brazil: deforestation in the Amazon increased 29% over last year [online]. https://news.mongabay.com/2016/11/brazil-deforestation-in-the-amazon-increased-29-over-last-year/ (accessed 8.6.17).

208 Noojipady, P., Morton, C.D., Macedo, N.M., Victoria, C.D., Huang, C., Gibbs, K.H. and Bolfe, L.E. (2017). Forest carbon emissions from cropland expansion in the Brazilian Cerrado biome. *Environmental Research Letters,* 12(2).

widespread regional problem. Cattle ranching is the cheapest way to make land claims on deforested land; and so the pasture expansion often seen along planned infrastructure developments such as highways (where land values are higher) reflects farmers' response to this insecurity.[209] Land speculation, often a lucrative form of organised criminal activity, also contributes to the problem: a recently convicted criminal gang is thought to be responsible for 10% of deforestation in Pará.[210]

That said, land tenure insecurity is unlikely to be the only explanation. Land use in Brazil has become increasingly regulated, as seen in the government's efforts to map all rural properties in a centralised rural cadaster.[211] And yet deforestation continues, albeit often at reduced levels even in regions where land has been consolidated and tenure established, such as in the southern Amazon and the Cerrado in Brazil. In the Cerrado, for example, much of the deforestation is legally permitted – land owners are entitled to clear 65–80% of their land, while in the better protected Amazon, the figure is only 20%.

Figure 15: Area proportion of deforestation driver in some countries of South America from 1990 to 2005 (%). From De Sy *et al.* (2015)[212]



Another way of assigning responsibility is to highlight the expansion of arable – and particularly soy – production in Brazil. As the grassfed movement points out, the growth in the global pig and poultry sector is mainly what drives this growing demand

[209] Gollnow, F., Göpel, J., Hissa, L. deBarros V., Schaldach, R. and Lakes, T. (2017). Scenarios of land-use change in a deforestation corridor in the Brazilian Amazon: combining two scales of analysis. *Reg. Environ. Change,* pp. 1-17. doi:10.1007/s10113-017-1129-1.

[210] BBC. (2014) Brazil dismantles 'biggest destroyer' of Amazon Rainforest. British Broadcasting Channel. Retrieved September 29, 2014 from http://www.bbc.com/news/world-latin-america-28961554

[211] CAR (2017). Cadastro Ambiental Rural [online]. http://www.car.gov.br/#/ (accessed 8.6.17).

[212] De Sy V, Herold M, Achard F, Beuchle R, Clkevers JGP, Lindquist E and Verchot L (2015). Land use patterns and related carbon losses following deforestation in South America. *Environ. Res. Lett*., 10(12). doi:10.1088. Reproduced under CC BY 3.0 (https://creativecommons.org/licenses/by/3.0/). The figure was not modified.

for arable output. There are both direct effects on deforestation (forests cleared for cropping) and more indirect ones too. As crops encroach onto pasture, they displace marginal beef producers into frontier regions at the forest margins. Since soil fertility in these regions is poor, an unholy dynamic is thereby set in motion, wherein new land is cleared as pasture fertility is exhausted.

While evidence in support of this analysis exists, one should not ignore the fact that demand for beef as well as monogastric meat is also growing, both domestically and outside Latin America. For example beef exports trebled in Brazil in the last 20 years, to around 20% of all production.[213]

And it remains the case that cattle-induced land use change continues to be more significant, in total area than that of the arable sector. Graesser *et al.* (2015)[214] look at trends in cropland and pastureland expansion across the whole of the Latin American region between 2001 and 2013. They find that the *rate* of cropland expansion is higher than that of pastureland. Compared with 2001 figures, the cropland area grew by about 77% whereas the pasture area expanded by only 37%. However, because the extent of pastureland is greater than of croplands, *in absolute terms* the total quantity of land converted to pasture is higher. On the whole, and with some regional exceptions, cropland largely tends to come from pasture, whereas new pasture land in taken from forest (see Figure 16).

Dias *et al.* (2016),[215] focusing on Brazil, make a similar point. They find that the total land area used for agriculture actually peaked in the 1980s and has remained fairly stable since then in net terms although land use change still continues, with some land abandoned (largely in the east) and new parts (mainly in the west) brought into cultivation (see Figure 17). However, within the cultivated area, land put to *cropping* has increased substantially, at the expense of natural pasture. But there has also been an increase in the area designated as planted pasture – natural grasslands that have been planted by non-native grasses, usually established after tilling, liming, and fertilizing the soil. In other words the natural savanna has been altered not just by conversion to cropping but by grazing system intensification. Demand for soy and maize to feed pigs, poultry, dairy cows and car engines is one driver of Cerrado loss – but so too are beef cattle, whose productivity has been boosted by soil amendments and the planting of 'improved' grasses such as *Brachiaria* spp. Rather than helping maintain the unique characteristics of the savanna, the grazing sector has undermined it.

213 Barbosa, F.A., Soares Filho, B.S., Merry, F.D., de Oliveira Azevedo, H., Costa, W.L.S., Coe, M.T., da Silveira Batista, E., Maciel, T.C., Sheepers, L.C., de Oliveira, A.R. and Rodrigues, H.O. (2015). Cenários para a pecuária de corte Amazônica. Universidade Federal de Minas Gerais, Belo Horizonte, MG.

214 Graesser, J., Aide, T.M., Grau, H.R. and Ramankutty, N. (2015). Cropland/pastureland dynamics and the slowdown of deforestation in Latin America. *Environ. Res. Lett.*, 10(3). doi:10.1088/1748-9326/10/3/034017.

215 Dias, L.C.P., Pimenta, F.M., Santos, A.B., Costa, M. and Ladle, R.J. (2016). Patterns of land use, extensification, and intensification of Brazilian agriculture. *Global Change Biology,* 22, pp. 2887-2903. doi: 10.1111/gcb.13314.

Figure 16: Changes in land use since 2001 attributable to cropping and pasture expansion in Latin America. From Graesser *et al.* (2015)[216]

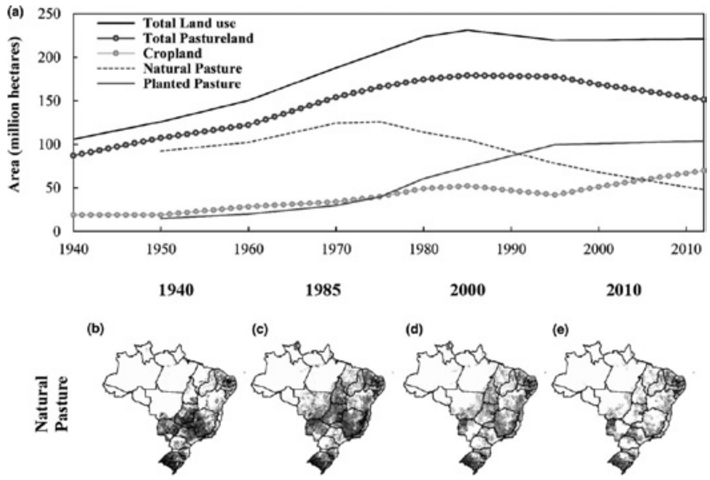
Note: This figure shows the area devoted to cropland and pastureland respectively (left and right hand column) in 2013 (hectares in boxes), and shows what the vegetation cover on this land was in 2001. In other words, it shows what the crop and pasture land in 2013 was taken from based on the situation in 2001. For example the top bar, the Latin American average, shows that most new cropland in 2013 came from what was originally pasture, although a small proportion was from forest or shrub land. Most of the new pasture land was from forest, with a small proportion from what was originally cropland, or from shrub. The overall pasture area is over three times larger than that of crops – so the impact is significant.

Different methodologies also exist which assign responsibility in different ways. For example, an indirect accounting method assumes that a product's deforestation footprint is proportional to how much its area has expanded, regardless of where it is planted, and how it is produced. In Brazil, for example, indirect accounting would give beef a deforestation footprint of zero, because the overall pasture area in Brazil is in

[216] Graesser, J., Aide, T.M., Grau, H.R. and Ramankutty, N. (2015). Cropland/pastureland dynamics and the slowdown of deforestation in Latin America. *Environ. Res. Lett.*, 10(3). doi:10.1088/1748-9326/10/3/034017. Reproduced under CC BY 3.0 (https://creativecommons.org/licenses/by/3.0/). The figure was not modified.

decline – even as new pasture is opened up in forested areas – while 20% of emissions from deforestation would be allocated to sugarcane, a crop that is actually associated with very little direct deforestation.[217,218] Indirect land use change may certainly be a reality in some areas but it is hard to quantify, and its estimation relies on several assumptions – notably that national agricultural commodity markets are near-perfectly integrated, and so that responsibility for land use change is assigned to crops in proportion to their expansion.[219]

Figure 17: Changes in land use in Brazil arising from cropland and planted pasture expansion. From Dias *et al.* (2016)[220]



In short, the drivers – or causes – of land use change are complex, and determining who or what is responsible depends in part upon the time-frame adopted, not to mention one's particular stance.

5.2.2 Europe

Crossing the Atlantic, Europe did its destructive work years ago; it does not 'need' to deforest more because its population is fairly stable as are its consumption patterns and – crucially in our globalised era – Europe can also export the deforestation problem by buying in agricultural products from overseas where labour costs are lower.[221] Thus, its forests are now expanding while the agricultural land area shrinks. These changes have benefited the soil carbon balance: an investigation into carbon

[217] Henders, S., Persson, U.M. and Kastner, T. (2015). Trading forests: land-use change and carbon emissions embodied in production and exports of forest-risk commodities. *Environ. Res. Lett.*, 10(125012). doi:10.1088/1748-9326/10/12/125012.

[218] Spera, S., VanWey, L., and Mustard, J. (2017). The drivers of sugarcane expansion in Goiás, Brazil. *Land Use Policy*, 66 (June 2016), pp. 111–119. https://doi.org/10.1016/j.landusepol.2017.03.037

[219] Persson, U.M., Henders, S. and Cederberg, C. (2014). A method for calculating a land-use change carbon footprint (LUC-CFP) for agricultural commodities – applications to Brazilian beef and soy, Indonesian palm oil. *Glob. Change Biol.*, 20, pp. 3482-3491. doi:10.1111/gcb.12635.

[220] Dias, L.C.P., Pimenta, F.M., Santos, A.B., Costa, M. and Ladle, R.J. (2016). Patterns of land use, extensification, and intensification of Brazilian agriculture. *Global Change Biology,* 22, 2887–2903, doi: 10.1111/gcb.13314

[221] Cuypers, D., Geerken, T., Gorissen, L., Lust, A., Peters, G., Karstensen, J., Prieler, S., Fisher, G., Hizsnyik, E. and Van Velthuizen, H. (2013). *The impact of EU consumption on deforestation: Comprehensive analysis of the impact of EU consumption on deforestation*. Brussels: European Union (Technical Report–2013–063).

fluxes on Europe's land over the past 60 years finds a steady process of sequestration thanks to an increase (by one third) in forest area and to cropland abandonment – the cropping area fell by about 18%.[222] Note that the net increase masks a possible soil organic carbon decline on European croplands, although this too is uncertain.[223]

As to the grasslands themselves, a separate study by Chang *et al.* (2016)[224] concludes that Europe's grasslands functioned as a carbon sink between the study period of 1991-2010 with the sink effect increasing over time. The authors largely attribute this to the reduction in grazing intensity brought on by falling ruminant animal numbers and, to a lesser extent, the increase in grassland area across Europe. This observation confirms the trade-off (highlighted in Section 3.5), between carbon storage and sequestration on the one hand, and livestock numbers on the other. Since overall meat consumption has not declined, this circle has been squared by an increase in intensive livestock production, both of the monogastric and ruminant kind. It is also important to note that, as in Brazil, the ecological quality of Europe's grasslands has also declined as semi-natural grasslands are 'improved'.

5.2.3 USA

The situation in the United States is different again. As for Europe, the big picture is one of forest cover increases and a declining agricultural area. But disaggregated analysis shows that while forests have regrown in Eastern regions, they have been cleared and prairies ploughed up in the West.[225] Large chunks of the prairies have in fact experienced a massive conversion to soy, wheat, maize and cotton in the last decade at rates not seen since the 1920s and 1930s, the US's era of rapid agricultural development.[226,227] The conversion of the prairies may be an important factor underlying the appeal of holistic grazing management. As public interest grows in the parallels to be drawn between the anthropogenic causes of the 1930s Dust Bowl and farming practices today,[228] the idea of an ecologically sensitive, carbon sequestering cattle rancher contrasts favourably in the public imagination with that of profit driven, high input-output industrial arable farmer.

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[222] Fuchs, R., Schulp, C.J.E., Hengeveld, G.M., Verburg, P.H., Clevers, J.G.P.W., Schelhaas, M.J.-J. and Herold, M. (2016). Assessing the influence of historic net and gross land changes on the carbon fluxes of Europe. *Global Change Biology*, 22, pp. 2526–2539, doi: 10.1111/gcb.13191.

[223] Ciais, P., Wattenbach, M., Vuichard, N., Smith, P., Piao, S.L., Don, A., Luyssaert, S., Janssens, I., Bondeau, A., Dechow, R., Leip, A., Smith, Pc., Beer, C., van der Werf, G.R., Gervois, S., Van Oost, K., Tomelleri, E., Freibauer, A. and Schulze, E.D. (2010). The European Greenhouse Gas Balance Revisited. Part 2: Croplands. *Global Change Biology,* 16, pp. 1409-1428. doi: 10.1111/j.1365-2486.2009.02055.x.

[224] Chang, J., Ciais, P.K., Viovy, N., Vuichard, N., Herrero, M., Havlik, P., Wang, X., Sultan, S. and Soussana, J.-F. (2016) Effect of climate change, CO_2 trends, nitrogen addition, and land-cover and management intensity changes on the carbon balance of European grasslands. *Global Change Biology,* 22, pp. 338–350. doi: 10.1111/gcb.13050.

[225] Ramankutty, N., Heller, E. and Rhemtulla, J. (2010) Prevailing Myths about Agricultural Abandonment and Forest Regrowth in the United States. *Annals of the Association of American Geographers*, 100(3), pp. 1–11.

[226] Wright, C.K. and Wimberly, M.C. (2013). Recent land use change in the Western Corn Belt threatens grasslands and wetlands, *PNAS*, 110(10), pp. 4134–4139.

[227] Follett, R.F. and Reed, D.A. (2010). Soil Carbon Sequestration in Grazing Lands: Societal Benefits and Policy Implications. *Rangeland Ecology & Management*, 63(1), pp. 4–15.

[228] McLeman, R.A., Dupre, J., Ford, L.B., Ford, J., Gajewski, K. and Marchildon, G. (2014). What we learned from the Dust Bowl: lessons in science, policy, and adaptation. *Population and environment*, *35*(4), pp. 417–440.

Box 13: Land use change, carbon release and livestock: some estimates of impact

The FAO's 2006 Livestock's Long Shadow[229] report attempted an estimate of emissions arising from livestock-induced deforestation. It calculated that emissions from extensive grazing systems – that is cattle – amounted to about 1.7 Gt CO_2-eq. Deforestation for feed production (to support intensive, often monogastric) systems contributed a further 0.7 Gt CO_2-eq. In all, livestock-induced land use change was estimated to account for around 34% of all livestock related emissions.

The FAO's subsequent 2013 report,[230] however, revised the deforestation estimate downwards substantially; while livestock related emissions as a whole were found to be similar to the original 2006 figure (both put the total at about 7 Gt CO_2-eq), the contribution of land use change calculated to be only 9.2%, of which extensive systems contributed two thirds (6% of the total).

There are several reasons for the difference in estimates. One of the main reasons is that reports used different versions of the IPCC guidelines, which resulted in substantially different estimates of carbon loss per hectare per year for land use conversion from forest to pasture and feed-crops. Differences in annual rates of conversion also contributed to the difference. These resulted first, from the use of different reference periods: 1990-2006 for the *Long Shadow* report, and 2000-2010 for the later one, during which time the rate of deforestation had slowed considerably; and second, the use of different data sources: the 2006 report mostly relied on Wassenaar *et al.* (2007),[231] while the 2013 report relied on interpretations based on FAOSTAT. Additionally, the 2013 analysis only estimated the impacts of land use change in Latin America and when looking at crop-induced changes, only considered soybeans since the impacts of other crops were judged to be very minor.

5.3 Emerging trends

These three regional examples – South America, Europe and the USA – show that what we use agricultural land for, how much of it we use, and the intensity with which we use it, are all changing, and they are changing differently in different parts of the world.

The question now is what the future will bring, and changes might be needed to create a future that we want. Perhaps the most obvious critical variables are how much more meat our global population will demand and of what kind, and on the supply side, how far livestock systems will continue to intensify.

While many environmentalists and academics argue that a more sustainable food future necessitates a cut in ruminant meat eating, in the future feared by many in the alternative grazing movement the real threat comes not from the maligned cow, but

[229] FAO (2006). *Livestock's Long Shadow*. Food and Agriculture Organisation, Rome.

[230] Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A. and Tempio, G. (2013). *Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities*. Food and Agriculture Organisation, Rome.

[231] Wassenaar, T., Gerber, P., Verburg, P.H., Rosales, M., Ibrahim, M. and Steinfeld, H. (2007). Projecting land use changes in the Neotropics: The geography of pasture expansion into forest. *Global Environmental Change*, 17(1), pp. 86-104.

from the plough. For them, agricultural intensification and the apparent convergence of global food cultures upon industrialised poultry meat and round-the-clock processed snacks mean that demand for cereals and oilseeds will grow. The cropping area will expand into the grasslands, whose conversion will release CO_2 and exacerbate dependence on fossil fuels – to produce fertiliser, for farm machinery and industrial infrastructure. An arable-based future will, in short, make things worse rather than better.

Obviously, it is impossible to predict the future. There can be sensible guesses, but the unexpected skews everything. Many forecasts described do indeed suggest that demand for meat – particularly that for poultry meat – will grow (Figure 18) and that crop and livestock systems will continue to intensify, but since the influences on production and consumption are hugely wide ranging, other futures are also possible, as discussed later on in this Chapter.

Figure 18: FAO projections for world livestock production by livestock sector. Adapted from Alexandratos & Bruinsma (2012)[232]

World	1961/1963	2005/2007	2050	1961–2007	1987–2007	1997–2007	2005/ 2007–2050
	Million tonnes			Annual growth (% p.a)			
Total meat	72	258	455	2.9	2.5	2.2	1.3
Beef	30	64	106	1.6	0.9	1.2	1.2
Mutton	6	13	25	1.7	1.8	2.1	1.5
Pigmeat	26	100	143	3.1	2.3	1.7	0.8
Poultry	9	82	181	5.2	4.7	3.9	1.8
Milk	344	664	1,077	1.4	1.3	2.2	1.1
Eggs	14	62	102	3.5	3.3	2.3	1.1

Both demand- and supply-side trends will be shaped by powerful forces – demographic, political, economic, cultural and biophysical, some of which can be altered if we want – and tempered by the other demands we place on land, whether to produce bioenergy or for new towns, cities, roads and factories. The FAO for example[233] identifies fifteen trends that will have a bearing on agriculture in the coming years. Some trends arise from within the sector but others, such as changes in the spread of pests and diseases, or the ebb and flow of conflict and migration, go way beyond the food system and could trigger non-linear changes both in demand and in supply. Other analysts identify possible game changing technological innovations within the food sector, such as artificial meat or novel non land-based feed sources that could have radical implications for future land use.[234]

Even assuming a business-as-usual 'intensive chicken' future, the consequences for land use are uncertain. Critical variables include the nature and pace of developments

[232] Alexandratos, N. and J. Bruinsma. (2012). World agriculture towards 2030/2050: the 2012 revision. ESA Working paper No. 12-03. Rome, FAO. Reproduced with permission.

[233] FAO (2017). *The future of food and agriculture – Trends and challenges*. Food and Agriculture Organisation, Rome.

[234] WRAP (2015). *Food Futures: from business as usual to business unusual.* Waste Resources Action Programme, Banbury, UK.

in agricultural productivity and innovation as well as, crucially, whether policies are put in place to influence food prices and protect land. Both will affect how much and what type of land we use and how intensively (Box 14).

Box 14: The complex interplay between livestock demand, livestock systems, agricultural innovation and the rebound effect

Ruminant production requires more land per unit of edible food output than monogastrics, but monogastrics consume more grains and soy – and therefore more arable land.[235] So, although increased demand for monogastric relative to ruminant meat will lower *overall* land requirements per unit of output, pressures on cropland may increase, while lessening on grassland.

However, the situation is complicated by several additional factors. For a start, cattle are currently the largest source of animal protein (taking meat and milk together) and are set to continue to be significant (see Figure 18 above) since demand is growing in absolute if not in relative terms. Given the size of the sector, even a small increase in beef or milk demand translates into high absolute increases in feed and associated land requirements, both arable (for mixed and landless systems) and for grazing.

At the same time, intensification in the ruminant sector will lead to greater feed conversion efficiencies. As a result, less land per unit of output will be needed, but on the other hand demand for arable land (to provide grain and oilseed protein) will grow.

The relationship between feed demand and arable land demand is, however, not of the 1:1 variety, given future uncertainties. Innovations in novel feeds – possibilities include mussel meal,[236] algae,[237] insects fed on waste streams[238] – and other feeds not requiring land could potentially alleviate some pressure on cropland. Yields may change too although by how much is unclear. Current yield improvement trajectories are likely to be dampened by climatic and other environmental changes[239,240] although there is always the possibility of a biotechnological or other agronomic breakthrough. The rate of change in crop and livestock productivity will critically determine how much if any new land is needed to produce the additionally required feed. This new land could come from existing grazing lands or from forest. Both options will have environmental consequences.

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[235] Mottet, A., de Haan, C., Falcuccia, A., Tempio, G., Opio, C. and Gerber, P. (2017). Livestock: On our plates or eating at our table? A new analysis of the feed/ food debate. *Global Food Security*, in press.

[236] McLaughlan, C., Rose, P. and Aldridge, D.C. (2014). Making the Best of a Pest: The Potential for Using Invasive Zebra Mussel (Dreissena polymorpha) Biomass as a Supplement to Commercial Chicken Feed. *Environmental Management,* 54(5). doi:10.1007/s00267-014-0335-6.

[237] Vigani, M., Parisi, C.R., Rodríguez-Cerezo, M., Sijtsma, L., Ploeg, M. and Enzing, C. (2015). Food and feed products from micro-algae: Market opportunities and challenges for the EU. Tr*ends in Food Science & Technology*, 42(1), pp. 81–92.

[238] Lalander, C.H., Fidjeland, J., Diener, S., Eriksson, S. and Vinnerås, B. (2015). High waste-to-biomass conversion and efficient Salmonella spp. reduction using black soldier fly for waste recycling Agron. *Sustain. Dev.,* 35(1), pp. 261–271.

[239] Challinor, A.J., Watson, J., Lobell, D.B., Howden, S.M., Smith, D.R. and Chhetri, N.I. (2014) A meta-analysis of crop yield under climate change and adaptation. *Nature Climate Change,* 4, pp. 287–291.

[240] Grassini, P., Eskridge, K.M. and Cassman, K.G. (2013). Distinguishing between yield advances and yield plateaus in historical crop production trends. *Nature communications*, 4.

It is important to note also that just because ruminants can be less arable grain-dependent than monogastrics, this does not mean that their existing use of grasslands is benign.[241,242] Meeting the anticipated growth in demand for ruminant meat and milk will also increase grass forage requirements. The options here are twofold: intensifying existing pastureland, or expanding into currently uncultivated areas – either ungrazed grasslands (where conditions are suitable) or forest. Both will cause environmental impacts.

There are also other things we might want to do with the land currently used for grazing. A large proportion of the grasslands livestock use has been formed from forest (they are not 'natural'), have little ecological value (consisting of fertilised grass monocultures) or may be degraded. That land could potentially be used for something else, including for nature conservation or for carbon sequestration by tree planting. At the same time, over a quarter of grassland is in fact suitable for cropping.[243] There will be a carbon loss if the land is ploughed up and the negative impacts in the US prairielands have already been noted. But since a relatively small area of cropland can produce the food output of a much larger area of grazing land, an argument could be made for sacrificing a small quantity of grassland to 'spare' the remaining grassland from intensification.

Of course, innovations in feed supply (for example the ability to process agricultural residues in such a way that monogastrics – including humans of course – are able to consume them) may also alter the feed-land demand relationship and affect judgements as to the merits of different animals and different production systems. Whey, for example, was once considered only good for animal feed but is now increasingly sold for human consumption.

Finally, and critically, the presence or absence of land controls, a carbon price or other environmental regulations will ultimately shape future configurations of land use. Without effective land controls, higher crop yields may not have a land sparing effect at all. The likely higher profits that ensue may simply incentivise further cropland expansion. Alternatively – or additionally – the cost savings will be passed down to the consumer, who will respond by buying more. The risk, then, is that the efficiency gains are swallowed up by overall increases in demand and supply.[244,245,246]

241 Mottet, A., de Haan, C., Falcuccia, A., Tempio, G., Opio, C. and Gerber, P. (2017). Livestock: On our plates or eating at our table? A new analysis of the feed/ food debate. *Global Food Security,* in press.

242 Peters, C.J., Picardy, J.A., Darrouzet-Nardi, A. and Griffin, T.S. (2014). Feed conversions, ration compositions, and land use efficiencies of major livestock products in US agricultural systems. *Agric. Syst*., 130, pp. 35-43.

243 Mottet, A., de Haan, C., Falcuccia, A., Tempio, G., Opio, C. and Gerber, P. (2017). Livestock: On our plates or eating at our table? A new analysis of the feed/ food debate. *Global Food Security*, in press.

244 Havlík, P., Valin, H., Mosnier, A., Obersteiner, M., Baker, J., Herrero, M., Ruffino, M. and Schmid, E. (2012). Crop Productivity and the Global Livestock Sector: Implications for Land Use and Greenhouse Gas Emissions. *American Journal of Agricultural Economics*, 95(2), pp. 442-448.

245 Baker, J., Murray, B.C., McCarl, B.A., Feng, S. and Johanson, R. (2012). Implications of alternative agricultural Productivity growth assumptions on land management, greenhouse gas emissions, and mitigation potential. Amer. J. Agr. Econ., 95(2), pp. 435-441; doi: 10.1093/ajae/aas114.

246 Garnett, T., Röös, E. and Little, D. (2015). *Lean, mean, green, obscene...? What is efficiency, and is it sustainable?* Food Climate Research Network, University of Oxford.

This point is illustrated in a study by Hunter *et al.* (2017), who look at the two best known projections for future crop demand (including for feed crops), both of which take a fairly conventional approach by extrapolating from current trends and linking demand to changes in GDP. According to one projection, crop demand between 2014 and 2050 will increase by 26%. The other projects an increase of 68%. This major divergence arises because the studies make different assumptions about GDP growth rates, the point at which Chinese demand for meat levels off, and how strongly socio-cultural factors will limit the growth in India's meat demand. The implications for future land use are profoundly different. Hunter *et al.* (2017) note that if the increase is only 26%, we could meet demand using existing cropland, even if the rate of improvement in agricultural productivity dwindles. With the higher demand scenario, the potential for doing so would be much smaller.[247]

Two other studies[248,249] also model what might happen to agriculture-related GHG emissions under different crop productivity scenarios, taking into account both direct and land use change-related emissions and both crop and animal emissions. They also factor in the effects of yield changes on crop prices and the extent to which livestock systems transition in response. Both indicate that productivity gains will reduce GHG emissions compared with baseline trends (although in absolute terms they will increase), even though livestock emissions rise. This is mainly because of land sparing effects, which reduce land use change-induced CO_2 and free up land for forestry. These mitigation benefits will be minor though, unless introduced together with specific climate mitigation and land control measures. The studies do not appear to factor in any lost sequestration effects arising from the decline in grazing systems. That is, they account for the negative impacts of converting grassland to cropping, but not the additional lost sequestration opportunity. However, since the mitigation potential from existing grasslands is so small and highly context-specific (see Chapter 3 above), this would be hard to do – and of course soil carbon losses from poor grazing management (which are common) would also need factoring in.

Smith *et al.* (2017)[250] use three of the IPCC's Shared Socio-economic Pathways (SSP) storylines as a basis for their livestock scenarios: SSP1, the most 'sustainable' one; SSP3, the 'rocky road' scenario; and SSP2, which approximates to business-as-usual. In SSP2, technology is anticipated to improve but without any major breakthroughs and agricultural systems evolve largely following FAO projections – the lower of the two highlighted by Hunter *et al.* (2017), above.

As Figure 19 shows, arable-based feed requirements increase for all scenarios by 2050 and again by 2100, with the share fairly evenly split between monogastrics and

[247] Hunter, M., Smith, R., Schipanski, M., Atwood, L. and Mortensen, D. (2017). Agriculture in 2050: Recalibrating Targets for Sustainable Intensification, *BioScience* bix010. DOI: https://doi.org/10.1093/biosci/bix010.

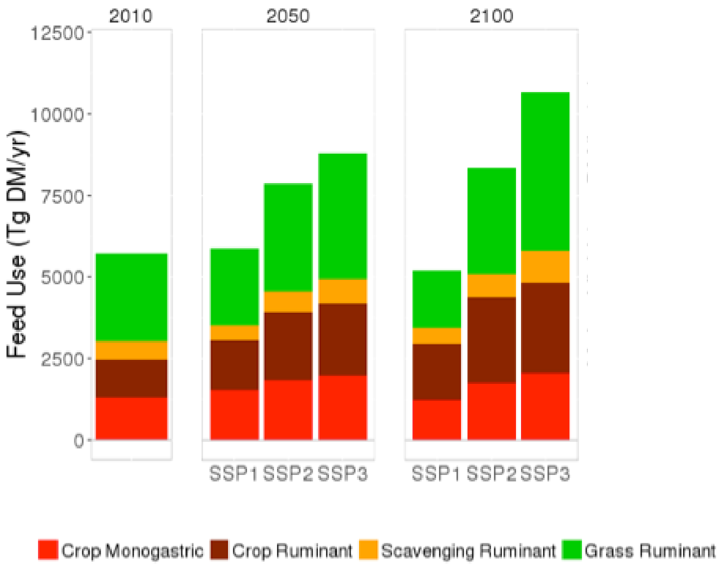
[248] Baker, J., Murray, B.C., McCarl, B.A., Feng, S. and Johanson, R. (2012). Implications of alternative agricultural Productivity growth assumptions on land management, greenhouse gas emissions, and mitigation potential. *Amer. J. Agr. Econ.*, 95(2), pp. 435–441. doi: 10.1093/ajae/aas114.

[249] Havlík, P.,Valin, H., Mosnier, A., Obersteiner, M., Baker, J., Herrero, M., Ruffino, M. and Schmid, E. (2012). Crop Productivity and the Global Livestock Sector: Implications for Land Use and Greenhouse Gas Emissions. *American Journal of Agricultural Economics,* 95(2), pp. 442–448.

[250] Smith, P., Nayak, D.R., Linthorst, G., Peters, D., Bucquet, C., van Vuuren, D.P., Stehfest, E., Harmsen, M., and van den Brink, L. (2016). Science-based GHG emissions targets for agriculture and forestry commodities. Final report to KR Foundation, October 2016, 86pp. Available at: http://www.ecofys.com/en/publications/science-based-ghg-emissions-targets/

ruminants. However, in SSP1 – a future where people cut back on meat and population growth is at the low end of projections[251,252,253] – overall feed requirements barely rise above the baseline in 2050 and actually fall below it by the end of the century, mainly because of lower grassland forage requirements, which in turn reflect reduced aggregate demand for meat as the human population stabilises.

Figure 19: Global demand for feed under different Shared Socio-economic Pathway (SSP) scenarios. From Smith *et al.* (2016)[254]



These are the projections for *feed* demand. Since all scenarios assume some increases in agricultural productivity, *land* requirements do not increase in exact proportion (Popp *et al.* (2017)[255] provides a general overview of land use futures in the different scenarios). In SSP1, both crop and pasture land needs actually fall (Figure 20 left image), which in principle frees up natural land (Figure 20 right image). Under the business-as-usual SSP2 scenario however, yield improvements do not sufficiently compensate for increased demand, causing a slight reduction in the natural land area.

[251] van Vuuren, D.P., Stehfest, E., Gernaat, E.H.J., Doelman, J.C., van den Berg, M., Harmens, M., Sytze de Boer, H., Bouwman, L.F., Daioglou, V., Edelenbosch, O.Y., Girod, B., Kram, T., Lassaletta, L., Lucas, P.L., van Meijl, H., Müller, C., van Ruijven, B.J., van der Sluis, S. and Tabeau, A. (2017). Energy, land-use and greenhouse gas emissions trajectories under a green growth paradigm, *Global Environmental Change*, 42, pp. 237–250.

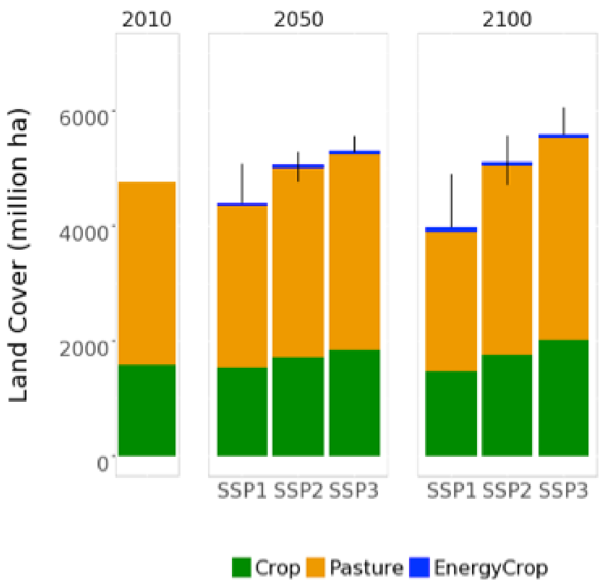
[252] Popp, A., Calvin, K., Fujimori, S., Havlik, P., Humpenöder, F., Stehfest, E., Bodirsky, B.L., Dietric, J.P., Doelmann, J.C., Gusti, M., Hasegawa, T., Kyle, P., Obersteiner, M., Tabeau, A., Takahashi, K., Valin, H., Waldhoff, S., Weinidl, I., Wise, M., Kriegler, E., Lotze-Campen, H., Fricko, O., Riahid, K. and van Vuuren, D.P. (2017). Land-use futures in the shared socio-economic pathways. *Global Environmental Change,* 42, pp. 331–345.

[253] Samir, K.C. and Lutz, W. (2017). The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100. *Global Environmental Change*, 42, pp. 181-192. doi: 10.1016/j.gloenvcha.2014.06.004.

[254] Smith, P., Nayak, D.R., Linthorst, G., Peters, D., Bucquet, C., van Vuuren, D.P., Stehfest, E., Harmsen, M., & van den Brink, L. (2016). Science-based GHG emissions targets for agriculture and forestry commodities. Final report to KR Foundation, October 2016, 86pp. Available at: http://www.ecofys.com/en/publications/science-based-ghg-emissions-targets/. Reproduced with permission.

[255] Popp, A., Calvin, K., Fujimori, S., Havlik, P., Humpenöder, F., Stehfest, E., Bodirsky, B.L., Dietric, J.P., Doelmann, J.C., Gusti, M., Hasegawa, T., Kyle, P., Obersteiner, M., Tabeau, A., Takahashi, K., Valin, H., Waldhoff, S., Weinidl, I., Wise, M., Kriegler, E., Lotze-Campen, H., Fricko, O., Riahid, K. and van Vuuren, D.P. (2017) Land-use futures in the shared socio-economic pathways. *Global Environmental Change,* 42, pp. 331–345.

Figure 20: Global demand for agricultural land under different Shared Socio-economic Pathway (SSP) scenarios. From Smith *et al.* (2016)[256]

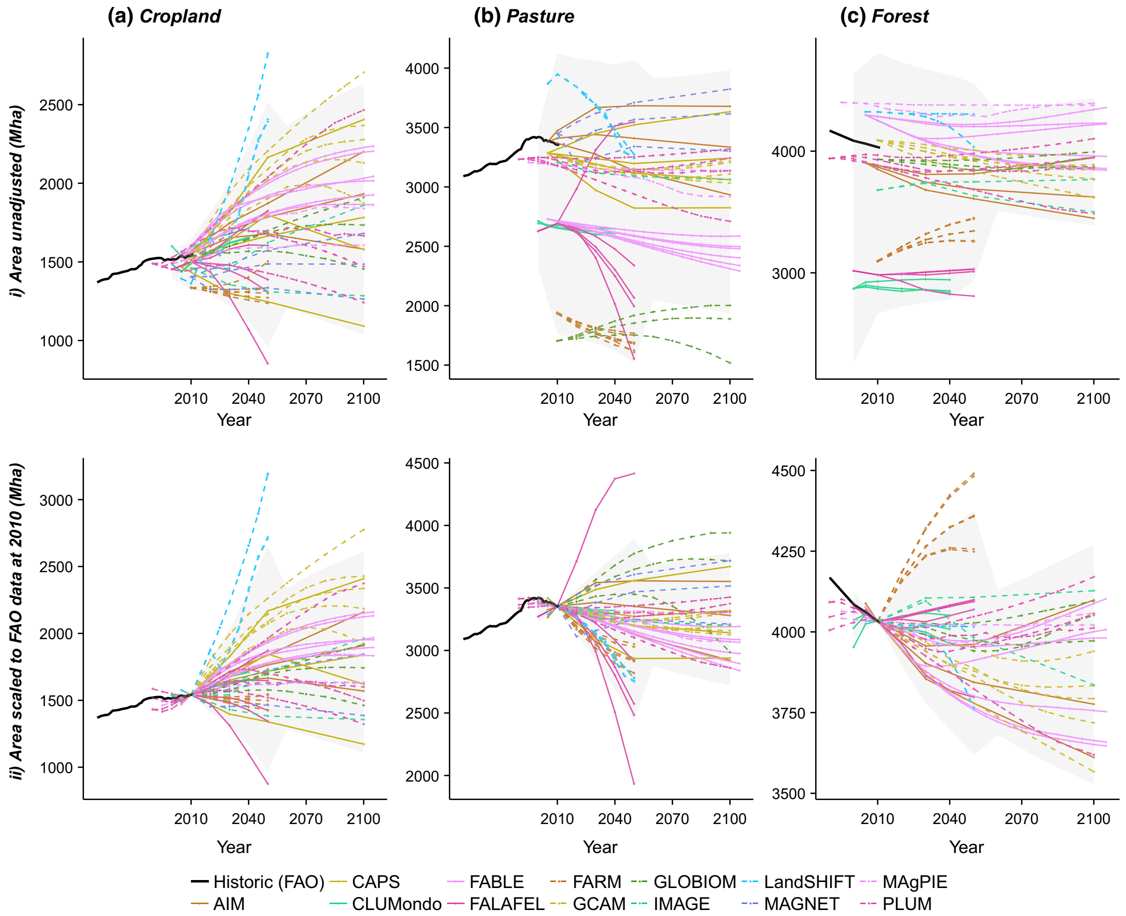


These are all individual studies, based on particular assumptions, data sources and simulation models. But there are many scenarios out there; Alexander *et al.* (2017) pulled them all together to see how they compared. All in all, the study looked at 75 simulations, based collectively on 18 models. The findings are striking. The different projections suggest very different land use trajectories, with the cropland extent showing the highest variability (Figure 21).[257]

[256] Smith, P., Nayak, D.R., Linthorst, G., Peters, D., Bucquet, C., van Vuuren, D.P., Stehfest, E., Harmsen, M., & van den Brink, L. (2016). Science-based GHG emissions targets for agriculture and forestry commodities. Final report to KR Foundation, October 2016, 86pp. Available at: http://www.ecofys.com/en/publications/science-based-ghg-emissions-targets/. Reproduced with permission.

[257] Alexander, P., Prestele, R., Verburg, P.H., Arneth, A., Baranzelli, C., Batista e Silva, F., Brown, C., Butler, A., Calvin, K., Dendoncker, N. and Doelman, J.C. (2017). Assessing uncertainties in land cover projections. *Global Change Biology*, 23(2), pp.767–781.

Figure 21: Global land use cover projections under different scenarios. From Alexander *et al.* (2017)[258]



Note: For all the models to have the same land-use area as starting points for 2010 (which allows for better comparison), Figures a, b and c are adjusted so that all the models have a common starting value based on FAOSTAT figures for the land use area. This, if anything, has the effect of increasing the range of uncertainty – the cropland, pastureland and forest areas could go up sharply, or down sharply.

These variations reflect differences in data sources; the way in which types of vegetation are categorised and subsequently their land area (especially forest versus grassland – see discussion in Section 1.3); as well as the purpose of the scenarios – whether they model what *might* happen or what *we may want* to happen.

In other words, the future is incredibly uncertain. Rather than trying to predict it, another approach is to consider sort of future we might want. What would a 'better' use of land look like?

[258] Alexander, P., Prestele, R., Verburg, P.H., Arneth, A., Baranzelli, C., Batista e Silva, F., Brown, C., Butler, A., Calvin, K., Dendoncker, N. and Doelman, J.C. (2017). Assessing uncertainties in land cover projections. *Global change biology*, 23(2), pp.767–781.

5.4 Future land use: some possibilities

Many advocates of grassfed production are highly critical of mono-cultural arable production, pointing out – with justice – that among other things, unsustainable mono-cropping practices for intensive livestock and human food consumption deplete soil carbon and in the case of soy cultivation, drive land use change. Croplands generally store less carbon than grazing lands, are highly input-dependent and less biodiverse.

In a land-constrained world, feeding animals on grains that could more directly be eaten by people is a wasteful use of scarce, good quality arable land and potentially exacerbates food insecurity. Instead, we need to remember what livestock are good at – consuming by-products and other feed sources that humans cannot eat directly and grazing on land that cannot be used for cropping, thereby avoiding feed-food competition – and we should reorient our production systems accordingly.

These are valid criticisms and shared by many within civil society and the academic community. Could, then, one model an alternative system that makes the most of livestock's resource recycling role and as such better reflects their ideas of what 'good' looks like? And what would be the implications for land use, GHG emissions, and food availability?

5.4.1 Livestock on leftovers: a grassfed future

Several studies (Schader *et al.*, 2015;[259] Van Zanten *et al.*, 2016;[260] Röös *et al.*, 2017[261]), in fact take concerns about feed-food competition – the feeding of human-edible grains to livestock – as the starting point for exploring the implications of an alternative relationship between livestock and resource use. Essentially each of these studies asks: if we avoided feeding animals human-edible feed and raised them mainly on: a) grassland unsuited to crop production; b) by-products arising from agricultural crop production; and c) food waste (the Schader *et al.* (2015) study excepted), how much meat, milk and eggs would we get to eat in 2050, given that the human population will by then have reached at least 9 billion?

The three studies make slightly different assumptions about, for example, grassland and livestock productivity; human diets (which influences what kind and quality of by-products and waste streams become available) food waste levels and utilisation, and they also differ in how they allocate feed stuffs between the animal species (see Table 6 for details). Nevertheless, they all come back with a similar answer to the 'how much?' question. This 'livestock on leftovers' approach does not produce enough meat, milk or eggs to meet projected global growth in demand. The per capita availability of animal protein these studies estimate varies from 11 to 32 g/person/day.

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[259] Schader, C., Muller, A., El-Hage Scialabba, N., Hecht, J., Isensee, A., Erb, K.-H., Smith, P., Makkar, H.P.S., Klocke, K., Leiber, F., Schwegler, P., Stolze, M. and Niggli, U. (2015). Impacts of feeding less food-competing feedstuffs to livestock on global food system sustainability, *Journal of the Royal Society Interface,* 12(113).

[260] Van Zanten, H.H.E., Meerburg, B.G., Bikker, P., Herrero, M. and De Boer, I.J.M. (2016). Opinion paper: The role of livestock in a sustainable diet: a land-use perspective. *Animal,* 10, pp. 547-549.

[261] Röös, E., Bajželj, B., Smith, P., Patel, M., Little, D. and Garnett, T. (2017). Greedy or needy? Land use and climate impacts of food in 2050 under different potential livestock futures. *Global Environmental Change*. In review.

The mean is about 21 g/person/day, which can be visualised as 100 g of raw bone-free meat/person/day but no milk – *or* 50 g of meat and 300 ml of milk, or some such combination. These are the figures before allowing for losses and waste.

Note that both van Zanten *et al.* 2016 and Röös *et al.* study 2017 include food waste as a feed source in their models. As a result their estimated protein availabilities – much of it derived from pork meat – are higher than that of Schader *et al.* 2015 who excludes food waste since its use is currently illegal in many parts of the world. This underlines the importance – also emphasised elsewhere[262,263] – of food waste as a livestock feed. Interestingly, Röös *et al.* 2017 also reruns their calculations, this time assuming that the Sustainable Development Goal of halving food waste is achieved. They find that animal protein availability drops considerably to 26 g/person/day. Note that that study – which gives the highest values of the three – additionally assumes that, to meet pigs' nutritional needs, some 30% of their diets consists of cereals.

The availability of ruminant protein specifically from grass – that is, from grazing systems – is substantially lower, amounting to between 7–18 g protein/person/day.

The current global average for per capita terrestrial animal protein availability is about 26 g, of which ruminants provide just under a half.[264] The reference or business as usual forecast for meat consumption in 2050 is 31 g.[265] Note that more than half the protein we consume actually comes from plant sources (see Section 1.2) and while the World Health Organisation recommends an average daily protein intake of approximately 0.83 g/kg of body weight/day, it does not specify the source – whether animal or plant-based.[266]

Clearly, there is huge variation in protein – and specifically in animal protein availability across the world: compare the Netherlands at 75.8 g/person/day for instance with Rwanda at 5.6 g/person/day.[267] In high income and increasingly in middle income countries, protein availability and indeed intakes are significantly in excess of requirements (see Box 15).

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[262] Zu Ermgassen, E.K.H.J., Phalan, B., Green, R. and Balmford, A. (2016). Reducing the land use of EU pork production: where there's swill, there's a way. *Food Policy,* 58, pp. 35–48.

[263] Van Zanten, H.H.E. (2016) *Feed sources for livestock: recycling towards a green planet*. ISBN: 978-94-6257-805-0. Wageningen University, the Netherlands.

[264] FAO (2016). FAOSTAT [online]. http://faostat.fao.org/ (accessed 17.5.16).

[265] Schader, C., Muller, A., El-Hage Scialabba, N., Hecht, J., Isensee, A., Erb, K.-H., Smith, P., Makkar, H.P.S., Klocke, K., Leiber, F., Schwegler, P., Stolze, M. and Niggli, U. (2015), Impacts of feeding less food-competing feedstuffs to livestock on global food system sustainability, *Journal of the Royal Society Interface,* 12(113).

[266] World Health Organization & United Nations University. (2007*). Protein and amino acid requirements in human nutrition* (Vol. 935). World Health Organization.

[267] FAO (2013). FAOSTAT [online]. http://faostat.fao.org/ (accessed 17.5.16).

Table 6: Livestock on leftovers – study findings and their assumptions[268]

Study	Feedsources used	Human diet modelled	Assumptions about waste	Animal productivity	Total animal protein, g/ person/day	Animal protein from grazing land only g/ person/day
Schader *et al.* (2015)	Pastures (3.38 Gha – utilisation rates derived from current feeding rations and animal numbers) Currently available by-product shares (oil-cake, brans, whey, etc.) applied to projected production volumes.	Projected average food energy intakes for 2050.	No food waste fed.	2050 forecasts by Alexandratos and Bruinsma 2012 – global average.	11 g of which 4 g is milk (cattle, sheep, goat, buffaloes), 1 g is non-ruminant meat (poultry and pigs), 3 g is ruminant meat (cattle, buffaloes, sheep and goats), 2 g is fish. Protein from eggs is negligible.	7 g
Van Zanten *et al.* (2016)	Pastures (3.34 Gha), 10% of food waste produced, co-products from a vegan diet.	A mainly vegan healthy diet with added animal products producible from associated waste streams, co-products and grazing lands.	Co-products available based on global consumption of a healthy largely 'default' vegan diet (i.e. co-product availability limited to what can be derived from this dietary pattern). Waste levels are assumed to be 10% all food produced (i.e. down from current levels); all food waste and co-products fed to pigs, ruminants 100% grassfed.	Global average for 2050.	21 (of which 7 g is milk and ruminant meat and 14 g is pork).	7 g
Röös *et al.* (2017)	Pastures (3.36 Gha – 30% forage offtake rate), food waste and co-products (fishmeal, oil cake, fibre-rich by-products) from seafood and plant-based foods in the projected diet in 2050 and food waste.	Business as usual projected diets.	Current waste levels continue as today. 30% cereals in pig diets to ensure nutritionally adequate pig diets; co-products to both pigs and ruminants. By-products and co-products available based on current global projected diets.	Swedish high end productivity for all livestock	32 (of which 9 g is milk, 9 g is ruminant meat and 14 g is pork).	19 g
Röös *et al.* (2017) – second scenario of above	Pastures (3.36 Gha – 30% forage offtake rate), food waste and coproducts (fishmeal, oil cake, fibre-rich by-products) from seafood and plant-based foods in the projected diet in 2050 and food waste.	Business as usual projected diets.	Waste reduced by 50%, 30% cereals in pig diets, co-products to both pigs and ruminants. By-products available based on a projected diet.	Swedish high end productivity for all livestock.	26 (of which 9 g is milk, 10 g is ruminant meat and 6 g is pork).	19 g

[268] Schader, C., Muller, A., El-Hage Scialabba, N., Hecht, J., Isensee, A., Erb, K.-H., Smith, P., Makkar, H.P.S., Klocke, K., Leiber, F., Schwegler, P., Stolze, M. and Niggli, U. (2015). Impacts of feeding less food-competing feedstuffs to livestock on global food system sustainability, *Journal of the Royal Society Interface,* 12(113).

Van Zanten, H.H.E. (2016). *Feed sources for livestock: recycling towards a green planet*. ISBN: 978-94-6257-805-0. Wageningen University, the Netherlands.

Röös, E., Bajželj, B., Smith, P., Patel, M., Little, D. and Garnett, T. (2017). Greedy or needy? Land use and climate impacts of food in 2050 under different potential livestock futures. *Global Environmental Change*. In review.

Box 15: Protein requirements and protein intakes: the UK as an example

Table 7 below shows average protein requirements for a typical British man or woman, as compared with the amount of protein they currently consume, both from all sources and from animal products alone. Intake data are taken from the National Diet and Nutrition Survey (NDNS) which is based on people weighing their food and filling in records; under-reporting is a significant and known problem and so actual animal protein intakes will very likely be higher. The final column shows animal protein supply per capita (before food losses and waste) based on FAOSTAT. This final figure is more directly comparable with the availabilities estimated by Schader *et al.* 2015, van Zanten *et al.* 2016 and Röös *et al.* 2017 (see main body of the text).

These figures are all subject to uncertainties but what they do show very clearly is that British people (men especially) eat more protein than they need, and – unsurprisingly in this high meat consuming country – animal sources contribute significantly to the protein total.

Note that the average Briton is also overweight; a reduction in the prevalence of obesity would also lower our protein requirements.

Table 7: Average British per capita protein requirements and intakes from all sources and from animal products alone.

Sex	Average weight (kg)	Protein requirements in g (all sources) based on 0.83 g/kg body weight	Current protein intakes in g (all sources) using NDNS data[269]	Current animal protein intakes excl. fish in g (% total protein) using NDNS data[270]	Animal protein supply in g using FAOSTAT data[271] (terrestrial animals only)
Women (UK)	70	58	65	34.5 (53%)	53
Men (UK)	83	69	85	47 (55%)	53

Source: National Diet and Nutrition Survey. Headline results from Years 1, 2, 3 and 4 (combined) of the Rolling Programme (2008/2009 – 2011/12), UK (Table 5.6)

The following thought experiments show that in a world where production systems were reconfigured to make the most of livestock's resource recycling role, animal protein availability would be limited.

269 Public Health England (2017). National Diet and Nutrition Survey - Results from Years 1, 2, 3 and 4 (combined) of the Rolling Programme (2008/2009 – 2011/2012). Edited by B. Bates et al. London. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/594361/NDNS_Y1_to_4_UK_report_full_text_revised_February_2017.pdf

270 *Ibid.*

271 For year 2013 - FAO (2017). FAOSTAT [online]. http://www.fao.org/faostat/en/#data/FBS (accessed 8.8.17).

5.4.2 Livestock on leftovers with holistic grazing: a thought experiment

Many advocates of holistic, rotational and related grazing approaches go a step further. They not only argue that ruminants are essential to a sustainable food future but that adoption of their grazing methods would increase livestock productivity significantly. Animal protein availability would therefore be significantly higher than the estimates given above.

To support these assertions, advocates may take as their exemplar some of the highly-acclaimed farms in the USA where stocking densities (on land that receives no mineral fertilisers and where the ruminants receive no feed supplements) are said to be as high as '400 cattle days per acre'.[272,273] In metric units, this is about 3 animals per hectare per year. In much of the world this stocking density would be an impossibility (see Table 8), but for the sake of the thought experiment, let us assume it can be achieved.

Table 8: Examples of average ruminant stocking rates in different livestock production systems and regions.

System	Ruminant stocking rate (animals/ha)
Intensive dairy production in European mixed systems	~1.8 – 2.2
Extensive Swiss Alpine grazing systems	~1
Intensive Neo-tropical beef grazing systems	Less than 1 on native grasslands. ~1-2.5 on improved pastures.
Extensive Northern Australian beef grazing systems	~0.02 on least productive native grasslands. ~0.3 on most productive native grasslands. ~1 on improved pastures.
Extensive Mongolian grazing systems	~0.1
Extensive African grazing systems	~0.1

Assuming a slaughtering age of two years and a carcass weight of 350 kg, a farm can deliver 400 kg of bone free meat per hectare per year.[†] If this productivity were achieved on all pastures globally, per capita annual meat availability in 2050 (for 9 billion people) would amount to 151kg, or around 80 g protein/person/day.[§] This is

[†] Calculated as follows: 3 cattle * 350 kg (carcass weight) * 0.75 (carcass weight to bone-free meat conversion) per 2 years (slaughtering age) = 400 kg bone-free meat per hectare per year)

[§] 400 kg of meat * 3.4 billion hectare of pasture / 9 billion people = 151 kg of bone-free meat per person and year

[272] Boye, K. (2016). How many acres do you need to raise cattle? (2016). [online] http://rethinkrural.raydientplaces.com/blog/how-many-acres-do-you-need-to-raise-cattle

[273] The Guardian (2010). Interview: Joel Salatin [online] https://www.theguardian.com/lifeandstyle/2010/jan/31/food-industry-environment

roughly the current global average per capita protein availability from all sources, both plant- and animal-based.[274] It roughly equates to 1000 calories' worth of food per day – about a third of our average daily requirements, assuming some food losses and waste. Since this scenario produces so much food, crop production on existing land would not need to be so intensive, meaning that use of fossil fuel based inputs could be lower.

To digress slightly – one could push the scenario a little further by hypothetically eliminating all arable production and converting croplands to grazing lands, the benefit being a substantial accumulation of soil carbon. However, since the global cropland extent is only half that of grassland this approach would not be able to provide all our food energy requirements even in this idealised world. And while they take issue with many of the nutritional and environmental arguments in favour of plant-based eating (see Box 16), even hard-core paleo advocates agree we need to some plant foods. As such, some cropping will continue to be necessary.

Box 16: What are some of the 'grassfed' arguments put against vegetarian diets?

In keeping with their critique of arable farming and their advocacy of grazing systems, grassfed advocates may additionally advocate a 'paleo' diet. This is a way of eating based around grassfed meat, animal fats such as butter and lard (but generally no other milk products), vegetables and – in moderation, because they are high in sugar – fruit. Carbohydrate rich foods are to be avoided – sugar obviously, but also cereals, potatoes and (in some variants), legumes. Some nuts may be permissible, others not. They argue that, contrary to mainstream environmental wisdom, plant-based diets do not offer a good alignment between health and environmental goals; ruminant meat-based diets offer far better nutritional value for environmental money.

While a great deal of research suggests that largely plant-based diets offer adequate nutrition at lower GHG 'cost' than more meat-based diets,[275,276,277] critics may counter these conclusions using two main arguments.

First, while plant-based foods may *on average* be lower in GHGs than animal products, this does not hold of all plant foods – some fruits and vegetables have high impacts.[278,279] The substitute effect – what people eat if they switch away from ruminant meat – rightly needs to be considered.

274 FAO (2016). FAOSTAT http://faostat.fao.org/ (accessed 17.5.16).

275 Hallström, E., Carlsson-Kanyama, A. and Börjesson, P., (2015). Environmental impact of dietary change: a systematic review. *Journal of Cleaner Production,* 91, pp. 1-11.

276 Aleksandrowicz, L., Green, R., Joy, E.J., Smith, P. and Haines, A. (2016). The impacts of dietary change on greenhouse gas emissions, land use, water use, and health: a systematic review. *PloS ONE*, *11*(11).

277 Heller, M.C., Keoleian, G.A., Willett and W.C. (2013). Toward a life cycle-based, diet-level framework for food environmental impact and nutritional quality assessment: a critical review. *Environ Sci Technol,* 47, pp. 12632-12647.

278 Tom, M.S., Fischbeck, P.S., Hendrickson, C.T. (2015). Energy use, blue water footprint, and greenhouse gas emissions for current food consumption patterns and dietary recommendations in the US, *Environment Systems and Decisions*, DOI: 10.1007/s10669-015-9577-y.

279 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 Nut*, 97, pp. 569-83.

Second, and linked to this, everything depends on the choice of functional unit. Animal products are generally richer than plant foods in readily bioavailable forms of not just protein, but also micronutrients such as iron, calcium, zinc, Vitamin A and Vitamin B12, and have fewer nutrient inhibitors such as phytic or oxalic acid. Taken as a bundled offering of nutrients – and measured against their carbon footprint using one of the available nutrient density indices (NDIs) – animal products, it is argued, compare less unfavourably with many plant foods.[280,281]

The NDI is a controversial metric since people (ideally) do not subsist on individual foods but rather on whole diets made up of many different kinds, each offering different nutritional benefits and disbenefits.

Moreover, while animal products are certainly rich in essential nutrients, in some forms they offer nutritional negatives too, such as saturated fat – although paleo advocates cite research saying that this nutrient has been unjustly maligned.[282] Processed meat (which paleo advocates also dislike) has been causally linked to cancer. The evidence on red unprocessed meat is more tentative;[283,284,285] some governments and scientists recommend that intakes should be limited, but the paleo movement vigorously reject the link with poor health.[286,287]

This balance of negatives and positives all in principle need to be incorporated into any assessment of animal products' nutritional contribution as compared with their climate impact. There will also be differences within animal product types – milk for example is rich in calcium but not iron, while lean chicken has less saturated fat than beef or lamb – which make a one size fits all functional unit for, or indeed judgement about, animal products difficult. Environmental studies draw different conclusions when they use different NDIs, each of which will weight individual nutrients differently and also vary in how they 'penalise' the negative contributions of undesirable nutrients.[288]

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[280] Smedman, A., Lindmark-Månsson, H., Drewnowski, A., Modin Edman, A.K. (2010). Nutrient density of beverages in relation to climate impact. *Food Nutr Res*, 54(1).

[281] Drewnowski, A., Rehm C.D., Martin, A., Verger, O.E., Voinnesson, M. and Imbert, P. (2015), Energy and nutrient density of foods in relation to their carbon footprint, *American Journal of Clinical* Nutrition. DOI: 10.3945/ajcn.114.092486.

[282] Malhotra, A., Redberg, R.F. and Meier, P. (2017). Saturated fat does not clog the arteries: coronary heart disease is a chronic inflammatory condition, the risk of which can be effectively reduced from healthy lifestyle interventions. Br J Sports Med Published Online First: 25 April 2017. doi: 10.1136/bjsports-2016-097285

[283] Micha, R., Wallace, S.K., Mozaffarian, D. (2010). Red and Processed Meat Consumption and Risk of Incident Coronary Heart Disease, Stroke, and Diabetes Mellitus: A Systematic Review and Meta-Analysis. *Circulation* 121, pp. 2271–2283.

[284] Etemadi, A., Sinha, R., Ward, M.H., Graubard, B.I., Inoue-Choi, M., Dawsey, S.M. and Abnet, C. (2017). Mortality from different causes associated with meat, heme iron, nitrates, and nitrites in the NIH-AARP Diet and Health Study: population based cohort study, *BMJ*, 357.

[285] Pan, A., Sun, Q., Bernstein, A.M., Schulze, M.B., Manson, J.E., Stampfer, M.J., Willett, W.C. and Hu, F.B. (2012). Red Meat Consumption and Mortality: Results from Two Prospective Cohort Studies. *Arch Intern Med.*, 172(7), pp. 555–563.

[286] Mark's Daily Apple (2012). Will eating red meat kill you? [online] http://www.marksdailyapple.com/will-eating-red-meat-kill-you/ (accessed 16.05.17).

[287] Robb Wolf (2012). Red meat: part of a healthy diet? [online] https://robbwolf.com/2012/03/14/red-meat-part-healthy-diet/ (accessed 16.05.17).

[288] Röös, E., Karlsson, K., Witthöft, C. and Sundberg, C. (2015), Evaluating the sustainability of diets–combining environmental and nutritional aspects. *Environmental Science & Policy*, 47, pp. 157–166.

Returning to the 'main' extreme scenario – if this vision of the future were not so implausible, things would look very promising indeed for food security. Until, that is, one considers the GHG implications: this level of livestock production will naturally also generate a concomitant increase in methane emissions, which requires sequestration levels to be high enough to compensate. Assuming three animals per hectare, each producing 50 kg of methane per year, methane emissions would amount to 150 kg per hectare.

Using the GWP over a 100 year time horizon as a metric, at three animals per hectare the rate of sequestration would need to be 1.1 tonnes carbon/ha (4.2 t CO_2/ha) – higher than all the peer-review estimates shown in Section 3.5 – to compensate for methane emissions alone. This rate would need to continue for as long as the livestock continued to be reared (which is impossible) and not be reversed either by human activity or by changes in the climate (which cannot be guaranteed). Of course, for a full GHG assessment one would also need to include N_2O emissions from excreta and CO_2 from fossil fuel use.

And then there are the trade-offs to consider. Considering environmental objectives alone, in some contexts and up to a point, improvements in pasture productivity and soil organic carbon levels will go hand in hand with biodiversity conservation and enhancement, but higher productivity can also work against biodiversity (a point to be discussed separately in our biodiversity report), particularly when nitrogen fertilisers or 'improved,' more productive grasses are used.

In short, this does not seem to be a solution, even if it were achievable.

5.4.3 Alternative uses for grazing land

The studies discussed above show that there are ways of obtaining animal protein that do not rely (much) on arable land. There are, moreover, studies concluding that at a population level, diets containing some (but limited) animal products in fact require less arable land than those that are purely vegan, since the additional food obtained from the grasslands and waste streams in the form of ruminant products reduces the need for food energy from arable land (Peters *et al.*, 2016[289]; Van Zanten *et al.*, 2016[290]).

But more land overall is used – and it is worth reiterating the point that grasslands are not an ecologically cost-free resource. Many grasslands receive fertiliser applications and other inputs, they may be ploughed periodically, and the pasture may be managed as a perennial monoculture. A production system that uses less arable but more grazing land may be *less*, but it may equally be *more*, damaging to the environment (across a suite of environmental indicators – with the net GHG balance just one of them) than one which uses more arable but less grazing land, depending on the specifics of the management regimes.

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[289] Peters, C.J., Picardy, J., Darrouzet-Nardi, A.F., Wilkins, J.L., Griffin, T.S. and Fick, G.W. (2016). Carrying capacity of US agricultural land: Ten diet scenarios. *Elementa: Science of the Anthropocene*, 4(1).

[290] Van Zanten, H.H.E. (2016). *Feed sources for livestock: recycling towards a green planet*. ISBN: 978-94-6257-805-0. Wageningen University, the Netherlands.

Crucially, there are counterfactual uses for grazing land to consider. The land could potentially be used in other ways, which would yield a different balance of costs and benefits for soil carbon sequestration, food provision and biodiversity conservation. The question then is, assuming that we need to derive sufficient and adequate nutrition from our land, which ways of configuring land might yield the most sequestration for the least GHG emissions cost?

Röös *et al.* (2016)[291] investigate this question for Western_Europe: they construct a range of eight hypothetical dietary and land use futures that differ from one another in what type, or whether animal products are consumed: 1) Business as Usual (BAU) – the types of meat we eat in 2050 are in similar proportion to what we consume today and the systems of production stay the same; 2) As BAU but we manage to improve crop yields and reduce waste (Y&W); 3) Also BAU but livestock systems intensify further (IL); 4) We cut down ruminant meat, and shift to poultry but continue consuming dairy products (and the ruminant meat that inevitably comes from that) (DP); 5) We avoid all terrestrial meat and replace with farmed fish, continuing to eat dairy (and meat from dairy systems) (DA); 6) A speculative scenario where we consume artificial meat and milk (AMD); 7) A plant-based future (PBE); and finally 8) A scenario where we consume only animal products that have been reared on by-products and land unsuited to cropping (EL) – although some winter feed is grown on arable land (which is why arable land use is nevertheless still higher than in the vegan scenario).

Each scenario has two dietary variants: in the 'projected diets' version the quantities of meat and other foods follow a BAU increase to 2050 while in the 'healthy diets' variant the diets adhere to dietary guidelines,[292] meaning that, among other changes, the meat component is lower than in the projected diets variant.

Figure 22, taken from the study, looks at how arable and overall land requirements vary under the different dietary variants. It shows that both arable and total land use requirements are lowest under the meat-free (PBE and AMD) scenarios.

[291] Röös, E., Bajželj, B., Smith, P., Patel, M., Little, D. and Garnett, T. (2016). Protein futures for Western Europe: potential land use and climate impacts in 2050. *Reg Environ Change* doi:10.1007/s10113-016-1013-4.

[292] These were taken from Bajželj, B., Richards, K.S., Allwood, J.M., Smith, P., Dennis, J.S., Curmi, E. and Gilligan, C.A. (2014). Importance of food-demand management for climate mitigation. *Nature Climate Change*, 4, pp. 924-929 doi:10.1038/nclimate2353, which in turn are based on a composite of recommendations from the World Health Organisation, the Harvard Medical School and the American Medical Association.

Figure 22: Alternative livestock futures: implications for land use. From Röös *et al.* (2016)[293]

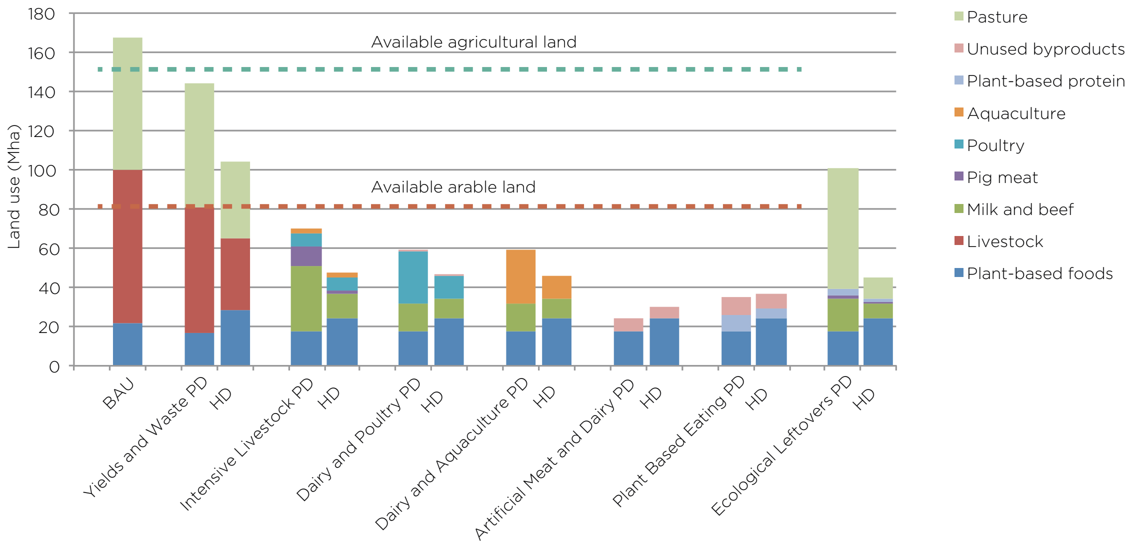
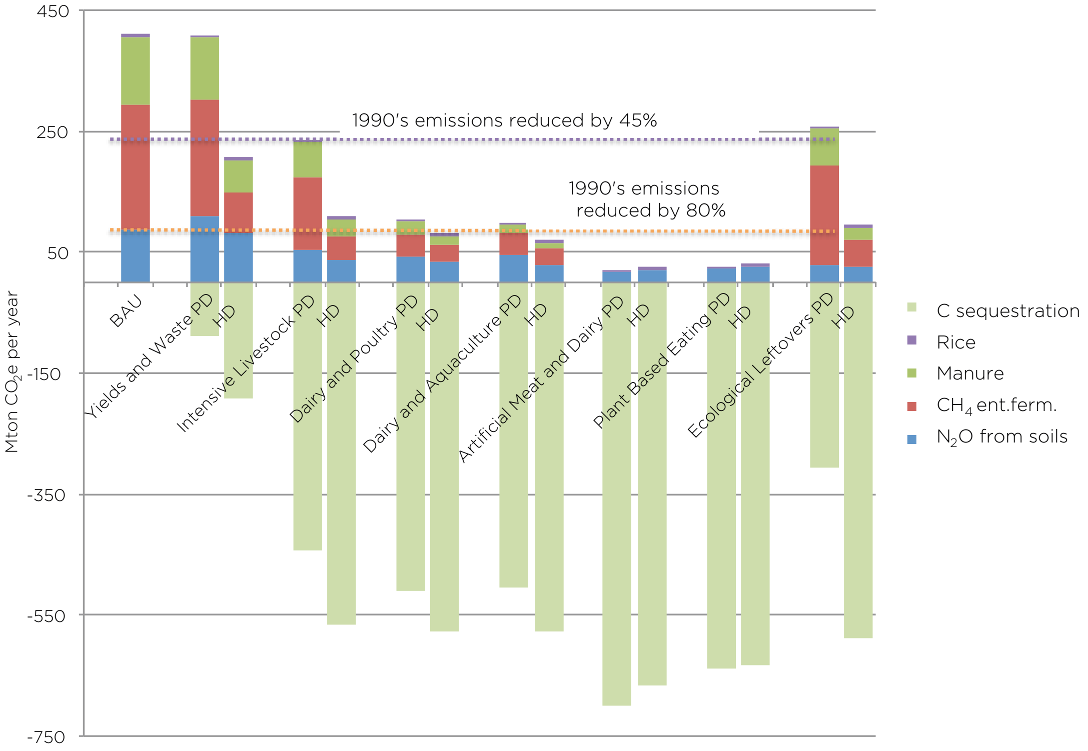


Figure 23 goes a step further. It plots the GHG emissions resulting from each scenario, as well as the sequestration potentially achievable on spared pasture or cropland. The artificial meat scenario, which is of course the most speculative, shows the greatest net reductions (emissions minus removals), followed by the plant-based future and then the dairy and aquaculture scenarios. Of course as emphasised elsewhere in this report, emissions and removals are absolutely not 'equal' in their importance, given issues of saturation, reversibility and leakage.

293 Röös E, Bajželj B, Smith P, Patel M, Little D and Garnett T (2016). Protein futures for Western Europe: potential land use and climate impacts in 2050. *Reg Environ Change*. doi:10.1007/s10113-016-1013-4.

Figure 23: Alternative livestock futures: implications for greenhouse gas emissions. From Röös *et al.* (2016)[294]



The study assumes that all foods consumed are produced within Europe and so takes no account of trade or any other economic variables. It also assumes that European soils are in carbon equilibrium (grazing or other agricultural management practices neither enhance nor reduce soil carbon) and only account for sequestration in the growing biomass via afforestation. Clearly, these are important simplifications and assumptions, all of which are open to challenge. There will also be massive economic and practical constraints as well as varied impacts for biodiversity depending on location and the approach to afforestation taken. Nevertheless, the study does provide some insight into what our options, biophysically speaking, might be. It also shows that, whatever the scenario, moderating meat intakes can both reduce GHG emissions and free up land: land that could potentially be used for rewilding, for biomass production, or that would allow us more leeway to farm in less intensive ways, using fewer chemical and mineral inputs.

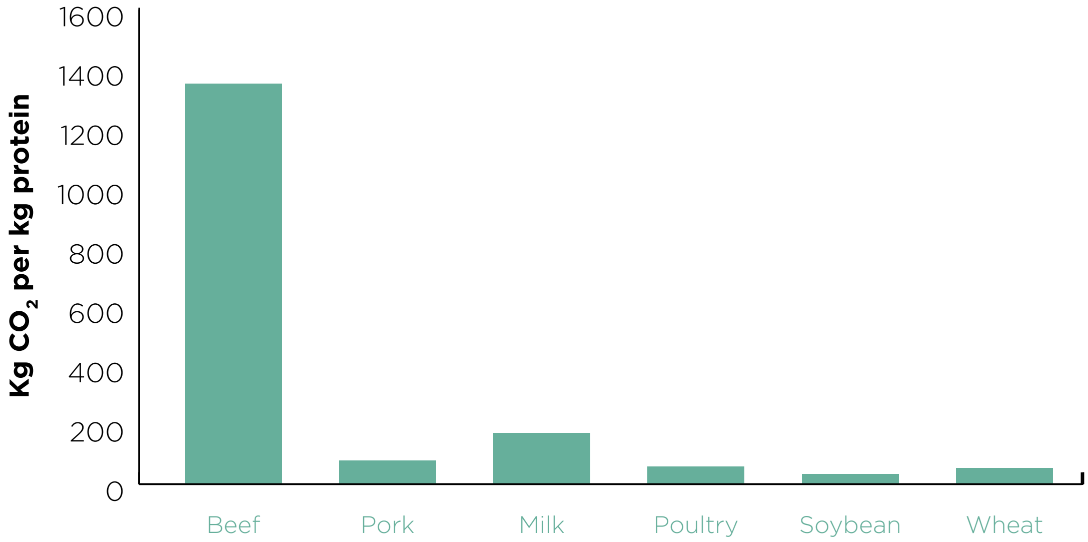
Smith *et al.* (2017)[295] take the idea of 'sparing land for sequestration' further by formalising its mirror image – the *foregone* sequestration potential – into a method for attributing land use impacts to different kinds of agricultural production. This carbon 'cost' of a given commodity equates to the carbon that could have been sequestered on the land were the land not being used to produce the commodity: in other words, it measures the opportunity cost of its production.

[294] Röös E, Bajželj B, Smith P, Patel M, Little D and Garnett T (2016). Protein futures for Western Europe: potential land use and climate impacts in 2050. *Reg Environ Change.* doi:10.1007/s10113-016-1013-4.

[295] Smith, P., Nayak, D.R., Linthorst, G., Peters, D., Bucquet, C., van Vuuren, D.P., Stehfest, E., Harmsen, M. and van den Brink, L. (2016). *Science-based GHG emissions targets for agriculture and forestry commodities.* Final report to KR Foundation, October 2016, 86pp. Available at: http://www.ecofys.com/en/publications/science-based-ghg-emissions-targets/

Figure 24 illustrates the study's results adapted to be more relevant for this report to show emissions per kg of protein rather than mass. On average animal (and particularly beef) related emissions are far higher than those of crops.

Figure 24: Global greenhouse gas emissions for various commodities per kg protein, expressed in CO_2-eq. Adapted from Smith *et al.* (2016)[296]



Note: Estimates do not take account of any changes in soil carbon stocks resulting from agricultural use, nor of direct methane, nitrous oxide or fossil fuel-related emissions.

This approach 'rewards' high yielding production which uses as little land as possible per unit of production, and penalises more extensive systems, particularly as it does not take account of changes in soil carbon stocks arising from different production practices. Its very 'either/or' attitude to production and sequestration is inimical to the 'both/and' approach advocated by grazing enthusiasts, and of course in many cases tree planting may not be the best approach for sequestration on some landscapes. Crucially, the idea that any land freed up really does get used for some environmentally desirable goal is of course questionable. Higher productivity – such as through a shift to more confined intensive animal production – can increase output. This may lower production costs and/or increase revenues, and also increase the availability and affordability of meat, potentially stimulating higher demand. All these factors may incentivise the cultivation of more hectares – a classic rebound effect. On the other hand, and more positively, more productive cultivation may put less productive systems out of business, so 'sparing' their production. Either way the effects are going to be context-specific and achieving positive outcomes will require effective policy governance.[297,298,299]

[296] *Ibid.* Reproduced with permission.

[297] Desquilbet, M., Dorin, B. and Couvet, D. (2016). Land Sharing vs Land Sparing to Conserve Biodiversity: How Agricultural Markets Make the Difference. *Environmental Modeling & Assessment*, pp.1-16.

[298] Phalan, B., Green, R.E., Dicks, L.V., Dotta, G., Feniuk, C., Lamb, A., Strassburg, B., Williams,D. R., zu Ermgassen, E. and Balmford, A. (2016). How can higher-yield farming help to spare nature? *Science*, 351, DOI: 10.1126/science.aad0055.

[299] Ewers, R.M., Scharlemann, J.P.W., Balmford, A., and Green, R.E. (2009). Do increases in agricultural yield spare land for nature? *Global Change Biology*, 15(7), pp. 1716–1726.

6. Conclusions

The rearing of livestock, both those in grazing systems and those that are not, positively and negatively affects people, society, the economy, and other aspects of the environment, as well as the animals themselves in a huge number of other ways. There are complex pathways linking animal production and consumption to human food security and nutritional status, to the spread of zoonotic diseases, to jobs, livelihoods, human development and power relations between genders. The rearing of animals for human use raises complex ethical issues. Animal farming and meat and milk consumption play important if differing roles in different societies and cultures. And then there are a whole host of environmental issues to consider – including the effects of animal production on biodiversity, and water cycling and use. Any one of these issues is enormous in itself and the subject of multiple contestations and debates – and we have not discussed them here.

Instead, this report has deliberately confined itself to a very narrow, albeit important and complex remit: that of grassfed ruminants in grazing systems, and their relationship with climate change, in relation to three main areas of contestation. First, it asks whether these animals can help soils sequester carbon and if so, how far this benefit counteracts their significant emissions. Second, it looks at some of the issues and beliefs about methane and nitrous oxide, and also looks at the consequences of ruminant production. Third, it looks at the historical and possible future role of grazing ruminants in driving damaging land use change and associated CO_2 release.

We attempt some conclusions here.

6.1 On the importance of defining terms

If any conclusions are to be drawn about ruminants in grazing systems, it is important to clearly specify what systems are actually being discussed. The ruminant livestock sector is highly diverse and the distinction between grazing and non-grazing systems is blurred. Some grazing systems are entirely autonomous, receiving no external inputs (apart from land) – in others either the livestock receive supplementary feed, or the grass itself receives various amendments. Animals also move between systems. There is no official definition of 'grassfed' beef or milk; a very 'pure' informal definition of grassfed may be meat produced from livestock fed entirely on grass grown on pastures that receive no mineral fertilizers, and reared at stocking rates that support environmental goals. The percentage of ruminants that are entirely reared in this way is unknown but likely to be very low; their contribution to overall animal protein supply lower still.

As to the grasslands that the animals graze, these are among the largest ecosystems in the world, occupying between 20–47% of the land area. They differ hugely as to their agro-ecological conditions, how they are managed and the scope for managing them. We do not even know exactly how much grazing land there actually is – our estimates are inherently imprecise.

6.2 On sequestration and the net GHG balance

6.2.1 Some topline numbers

Annual emissions from all anthropogenic sources stand at about 49 Gt CO_2-eq/yr.[300] Livestock supply chain emissions contribute about 14.5% of this total at 7.1 Gt CO_2-eq/yr (1.9 Gt C-eq), with most of the emissions generated at the agricultural stage. Of this, about 80% is attributable to ruminants.

Ruminants in *grazing-only* systems emit about 1.32 Gt CO_2-eq, or 20% of the livestock total (a figure that includes supply chain and land use change-related impacts). Since they account for only a fraction of the meat produced globally, supplying about 1 g of protein/person/day this means that per unit of protein output, their emissions intensity is very high. Note that since grasslands play a significant role in mixed crop-livestock systems too, the contribution of *grasslands* to human protein supply is higher but difficult to estimate, and complicated by the fact that animals in these systems may also be fed grains as well as agricultural by-products. The terrestrial livestock sector as a whole contributes 27 g protein/person/day while plant sources provide the bulk of human protein intakes today.

These are their emissions. The question is, could grazing ruminants also help sequester carbon in soils, and if so to what extent might this compensate? As the following numbers show, the answer is 'not much'.

Global (as opposed to regional or per hectare) assessments of the sequestration potential through grassland management are actually few and far between, but range from about 0.3-0.8 Gt CO_2/yr[301,302,303] with the higher end estimate assuming a strong level of ambition.

This potential offsets 20-60% of emissions from grazing systems: 4–11% of total livestock emissions, and between 0.6 and 1.6% of total annual greenhouse gas emissions – to which of course livestock also substantially contribute.

[300] IPCC (2014). *Summary for Policymakers*. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[301] Henderson, B.B., Gerber, P.J., Hilinski, T.E., Falcucci, A., Ojima, D.S., Salvatore, and M. and Connant, R.T. (2015). Greenhouse gas mitigation potential of the world's grazing lands: Modeling soil carbon and nitrogen fluxes of mitigation practices. *Agriculture, Ecosystems and Environment,* 207, pp. 91–100.

[302] Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M., Smith J. (2008). Greenhouse gas mitigation in agriculture. *Philos Trans R Soc*, 363(1492), pp. 789-813.

[303] Herrero, M., Henderson, B., Havel, P., Thornton, P.K., Smith, P., Wirsenius, S., Hristov, Gerber, P., Gill, M., Butterbach-Bahl, K., Vain, H., Garnett, T. and Stehfest, E. (2016). Greenhouse gas mitigation potentials in the livestock sector, *Nature Climate Change*, 6, pp. 452-461.

6.2.2 Practices and their contexts

There are of course many reasons for managing grasslands better in regions across the world – for instance to support other environmental goals, such as biodiversity conservation, or to improve the livelihoods of often marginalised communities.

That said, our report has focused narrowly on the question of carbon. It finds that well-managed grazing systems can aid the process of soil carbon sequestration. Indeed, in some regions, quite high levels of sequestration are possible for a few years or decades – giving rise to some fairly extravagant claims when extrapolated over continents and indefinite time-frames. But the potential is highly context-specific. Critical variables include climate, terrain, soil quality, grass species composition, past land use and management and more, as well as the present management approach. Sequestration is not possible everywhere and gains in one season can also be reversed in another.

The relationship between soil carbon sequestration and grazing intensity is complex. In soils that are not in equilibrium and where climate and other agro-ecological factors are favourable, light to moderate intensity grazing tends to promote sequestration. However, distinctions between levels of intensity tend not to be clearly defined and will depend upon context, sometimes at an extremely granular level. An intensity that is considered low in one context may be much too high in another.

There is some evidence to suggest that in some cases, grassland can store more carbon than forests. Thus, keeping ruminants on the land can achieve greater sequestration than removing them altogether and allowing woody vegetation to encroach. But on many lands, reversion to their natural wooded state will likely achieve higher levels of sequestration than will grazing although the (small) foregone food value of the grazing animals may need to be compensated for elsewhere.

The sequestration potential is generally greater on currently degraded lands since there is more room for improving management practices and 'restoring' the carbon stock, but low rainfall levels may be a limiting factor, and the economic and logistical obstacles will often be greater. On soils that are already in good condition, while a switch to poor management could cause huge carbon losses, good grazing management will not sequester much, if any, more carbon.

Overgrazing – defined here as grazing over durations or at stocking densities higher than the land can support – damages soils, leads to soil carbon losses and undermines the provision of other ecosystem goods and services. Where soils are over-grazed, reductions in grazing pressure – including by removing the animals altogether if necessary (at least until the vegetation recovers) – can help restore soils and benefit the environment in other ways too.

As to the timing of grazing: there is no clear evidence that by-the-book rotational grazing is better than continuous grazing. When it comes to more 'holistic'[†] variants of this approach, which rotate animals but also incorporate other management practices and objectives, the evidence is scanty, contradictory and either way the sequestration numbers involved are small. Such benefits as are found may reflect the fact that these practices tend to attract unusually motivated and attentive farmers whose goals often go beyond achieving profits – leading to the somewhat circular conclusion that good

[†] terms include regenerative, adaptive holistic, mob, and management intensive intermittent grazing

managers manage well and raising question about the potential for scalability. We recognise that more research is needed and that absence of evidence is not the same as evidence of absence of an effect.

Essential to note is that since soils reach carbon equilibrium after a few decades, any sequestration that good grazing management (or any other land management practice) can achieve will be time limited. The methane problem, however, continues for as long as the livestock are on the land (of which more below).

There are of course other good reasons why one might want to build soil organic matter: soils rich in carbon have the additional benefit of fostering soil fertility and health, so aiding greater agricultural productivity and adaptation to climate change. On the other hand, a narrowly sequestration-first approach can undermine other goals. What is optimal for sequestration may not be so for biodiversity or for other environmental goals – issues we will explore in more detail in companion reports to this. Social, institutional and economic considerations, not discussed here, add a further layer of complexity.

Whatever the scope for sequestration, essential to emphasise is the importance of ensuring that grazing management – and indeed all agricultural management – *keeps existing carbon in the ground and vegetation*. Released carbon causes permanent warming. Avoiding carbon release is therefore even more important than trying to sequester it.

6.3 On methane and nitrous oxide

6.3.1 Methane

Ruminants emit methane: they generate about a third of all global anthropogenic methane emissions. Methane emissions tend to be higher, per unit of food output, in grazing than in mixed or landless systems.

Methane is a powerful greenhouse gas. But while it has a stronger immediate warming effect than CO_2, it has a shorter atmospheric life span. The effect of a given pulse of methane is temporary, unless replaced by another pulse. In contrast CO_2's warming effects are weak, but since they are *de facto* permanent, the next pulse of CO_2 emitted adds to the warming effects of what was emitted before. So, because of their differing lifespans, a constant emission of CH_4 is therefore equivalent to one-off release of CO_2.

Nevertheless, while methane may have a short atmospheric lifetime, its effects are not ephemeral *provided the source of the methane continues to exist*. For as long as livestock continue to be farmed, methane continues to exert a warming effect upon the climate. As such the argument that since methane's impacts are temporary, they do not matter, is wrong. Its effects will in practice be permanent, unless ruminant production is halted. Methane emissions also increase the risk of us 'overshooting' the 1.5°C/2°C target, potentially tipping us into unknown climatic territory, with possibly devastating effects on agriculture, wildlife's ability to adapt, heat stress in humans and animals, and more.

Sometimes the debate about intensive confined production versus extensive grassfed systems is framed as one of fossil fuel engendered CO_2 versus 'natural' CH_4. This is unhelpful because it is inaccurate. Notwithstanding wide variation in their energy intensity, almost all livestock systems – apart from those that are totally disconnected from markets – rely on fossil fuels, including grazing systems. Scaling grazing systems up to produce a level of output that could substitute for the outputs of intensive confined systems so as to meet the projected demands of a growing population would have very damaging consequences for land use change and associated CO_2 release.

Reductions in GHGs *of all types* are urgently needed. We are not in a position to be selective.

6.3.2 Nitrous oxide

Nitrogen is essential to plant and animal growth and maintenance. Nitrogen is abundant in the atmosphere as N_2 but for plants to use it, it needs to be available in the soil in reactive forms. Some plants (legumes), algae and some bacteria can fix atmospheric nitrogen. The widely used alternative is to capture nitrogen via the highly energy intensive Haber-Bosch method.

Under the right conditions, nitrogen readily converts into many forms, one of which is nitrous oxide, a greenhouse gas that is both extremely potent (265 times more so than CO_2) and relatively long lived.

Since soil carbon sequestration is ultimately a consequence of plant growth (which can be aided by grazing management) and since plants need nitrogen to grow, it follows that the carbon and nitrogen cycles are closely bound together in the terrestrial ecosystem. Actions to increase soil carbon sequestration require the presence of nitrogen and since reactive forms of nitrogen in soils readily convert into N_2O, the risk is that adding it to soils to promote growth and foster soil carbon sequestration also leads to emissions of N_2O. Nitrogen can also increase soil carbon release into the atmosphere. Sometimes the global warming effects of the N_2O will outweigh the sequestration gains; nitrogen also causes other environmental problems such as water pollution.

Much is made of ruminants' role in cycling nitrogen, and in particular of the fertilising effects of their dung. However, while animal manure has the virtue of delivering nitrogen (and other nutrients) to soils in a form that is readily available to plants, it is important to emphasise that they do not add any *new* nitrogen to the system. It simply redeposits the nitrogen previously already embodied in the plant matter grown locally, or imported from elsewhere in animal feed. The nitrogen cycle is a leaky one – there are losses in the form of exported milk, meat and animal carcass, and there will be losses to waterways. Ruminant manure is not – as it were – a free lunch.

6.4 On land

The area devoted both to grazing and to cropping has increased dramatically over the course of human history. The rangeland and pastureland area is approximately double that of cropland and takes up about a quarter of the global land surface.

While some grasslands are natural, many of the grazing lands used today were formed at great environmental cost from what was originally forest. Grazing livestock have historically been the main agent of anthropogenic deforestation and associated CO_2 release.

Today the rate of land use change is slowing in aggregate, in part because of gains in productivity, but deforestation – induced by ruminant livestock as well as other drivers – continues apace in many parts of the world, with the aggregate extent of the damage disguised by afforestation elsewhere.

Importantly, the nature of land use change has also shifted. Although forests are still threatened, grasslands, with their enormous carbon stores, are increasingly at risk. One threat comes from the arable sector: demand for soy and grains is driving grassland conversion and the release of its stored carbon into the atmosphere. However, the grazing sector is another source of threat, as grasslands are intensified to support higher livestock numbers. While this process of intensification may not cause a loss of soil carbon, the use of fertilisers generates N_2O emissions (on top of the methane that the animals emit) and biodiversity is diminished. Arguments, then, that large natural grassland biomes such as the Cerrado, or the semi-natural grasslands found in Europe have been destroyed by cropping are only half-true – damage has also been caused by the grazing sector itself in the rush to squeeze more from the land.

As to future land use change, there are so many factors to consider here – from agronomic developments, wildcard innovations such as artificial meat and cultural shifts, through to the possibility of wars and plagues – which means predictions are almost certainly going to be wrong. Even the tamer models suggest a very wide range of futures, based not just on different data sources, and what are judged to be the most important drivers of change but also on differences in the questions they are seeking to answer.

Assuming a business-as-usual trajectory of eating more meat – and in particular more intensively reared monogastric meat – while models suggest that the relative influence on land of cattle reared in grazing systems will diminish over time, the consequences for land use are not clear cut. Much will depend upon factors such as the rate of gains in agricultural productivity, the pace of global economic growth, the effects of climate change and the extent to which carbon pricing, land controls or other policies are put in place to limit land use change.

One risk is that we will use land more ‘efficiently’ than before, if efficiency is very narrowly defined in terms of animal protein output per unit of land, but grasslands will be lost unless yield improvements manage to keep up with the increase in feed-crop demand. Productivity gains can both increase and reduce demand for land use: they can reduce them because less land is needed per unit of output, but they may also increase demand via the rebound effect – greater productivity can lead to greater profits, which can stimulate further expansion of activity, unless policies are introduced to counter this effect. The prospect of an industrialised white meat future could not only cause further grassland conversions and exacerbate pressures on existing arable land but would also raise other very serious concerns. Some are environmental but there are many other issues too, which this report has deliberately not discussed. These include the ethical and welfare problems of highly intensive systems, issues such as antimicrobial resistance and zoonotic disease transmission, poor working conditions, and health and nutritional concerns.

At the same time, a counterfactual scenario – a world where grazing ruminant systems were to supply all our meat demand – would be equally problematic. This future requires a massive expansion of grazing land, which would inevitably occur at the expense of forest cover, and a massive increase in methane emissions.

What is more, while 'grassfed' animals may not be dependent on arable-based feeds, the supposition that they are using spare land that could not be used for something else is mistaken.

Our land is finite. We have already disturbed too much of it, mostly to produce food. This includes grasslands as well as croplands: land that is used to graze animals could potentially be used for something else – for food, for nature conservation, for forests, or for bioenergy. There are almost always alternatives: the question is, what do we want?

If the goal, for example, is to use land in ways that deliver maximum environmental gain while also ensuring adequate nutrition for our global population, then several options present themselves.

We might choose, for example, to base farming systems on what animals, particularly ruminants, are 'good' at. They are good at recycling residues and crop by-products and making use of land that can less easily be cropped in order to provide us with food. The studies reviewed in this report suggest that this 'ecological leftovers' approach to livestock production – grasslands plus a substantial contribution from feeding monogastrics food waste – could provide a population of 9 billion with about 20 g animal protein (from all types) per person per day – much less than current Western consumption levels and below the anticipated global average of 31 g in 2050, but nevertheless a useful amount.

Yet another strategy might be to prioritise biodiversity:[304] to graze animals in ways and only on locations where they actively foster or protect biodiversity[†]. How much food would a biodiversity-first approach give us to eat? We do not know, but the question is important, given the rapid rate of species loss, and will form the subject of our next report.

[†] How one assigns value to biodiversity is a huge question in itself and one we will reserve for our subsequent report

[304] Röös, E., Patel, M., Spångberg, J., Carlsson, G. and Rydhmer, L. (2015). Limiting livestock production to pasture and by-products in a search for sustainable diets. *Food Policy,* 58, pp. 1-13. http://dx.doi.org/10.1016/j.foodpol.2015.10.008.

6.5 Some concluding remarks

Leaving aside for the moment any conclusions about the potential of livestock to help *solve* our environmental problems, the livestock systems that operate today cause an enormous amount, and many kinds of, environmental damage. To raise the animals we eat and use, we have cleared forests, driven species to extinction, polluted air and waterways, and released vast quantities of GHG emissions into the atmosphere. The rearing of animals has literally transformed the face of this earth.

Of course animal farming has also brought humanity huge benefits:[305] which is why we rear them and why the sector is growing today. It provides food that is highly nutrient dense, much liked and culturally significant. Farm animals can convert biomass that humans cannot eat into food that we can. They provide income, livelihoods and in some parts of the world livestock keeping constitutes a survival strategy. In days and places where population densities were or still are sufficiently low and land abundant, livestock played, and continue to play, an important role in transferring nutrients from grasslands and onto cropland via their manure. But this role is now diminishing. Land constraints and population growth mean we can no longer rear animals in traditional ways while *also continuing to fulfil an ever-growing demand for animal product*s. That reality has triggered the development of new production systems that may be more environmentally efficient in some respects[306] but that also generate a whole new set of problems.

It is, of course, possible to rear *a limited* number of animals in ways that cause less damage. This report, which focuses on just one environmental concern – climate change – has found that well-managed grazing in some contexts can cause carbon to be sequestered in the soil – and at the very least can provide an economic rationale for keeping the carbon in the ground. It is important to identify what and where those contexts are, a point discussed further in our research recommendations. But at an aggregate level the emissions generated by these grazing systems still outweigh the removals and even assuming improvements in productivity, they simply cannot supply us with all the animal protein we currently eat. They are even less able to provide us with the quantities of meat and milk that our growing and increasingly more affluent population apparently wants to consume. Significant expansion in overall numbers would cause catastrophic land use change and other environmental damage. This is especially the case if one adopts a very 'pure' definition of a grazing system, the sort that grazing advocates tend to portray, where livestock are reared year-round on grass that is not fertilised with mineral fertilisers, receiving no additional nutritional supplementation, and at stocking densities that support environmental goals.

That said, it does not follow that intensive production systems offer a better alternative. The shift to intensification changes the nature of the problems, and by some measures, makes things worse.

Of course all food production has damaging impacts, as compared with a baseline of no human presence on the planet. And in many parts of the world there will be good

[305] Livestock Global Alliance. (2016). Livestock for Sustainable Development in the 21st Century. Available at: http://www.livestockglobalalliance.org/wp-content/uploads/2016/05/LGA-Livestock-for-SDGs.pdf

[306] Davis, K.F., Yu, K., Herrero, M., Havlik, P., Carr, J.A. and D'Odorico, P. (2015). Historical trade-offs of livestock's environmental impacts, *Environ. Res. Lett.*, 10(12).

nutritional and developmental reasons to support some livestock production as part of a suite of approaches aimed at ensuring adequate nutrition from sustainable food systems. At the same time the ongoing assumption that production needs to meet the demands of high consuming individuals in affluent countries and increasingly in other parts of the world too needs questioning.

The challenge for now and the coming years is to figure out the environmentally 'least bad' way of using land and other resources to nourish ourselves and meet our other developmental goals. In some contexts, it may well be better to use the land and other resources to graze animals, than to do something different with them. In a few parts of the world, grazing systems are the only means by which local communities obtain food. Occasionally, grazing animals may even actively foster environmental objectives rather than just constitute a lesser evil and it is important to identify in which contexts this applies. But often there will be alternative uses for that land, alternatives that are possible and preferable depending upon the criteria chosen.

The inescapable conclusion of this report is that while grazing livestock have their place in a sustainable food system, that place is limited. Whichever way one looks at it, and whatever the system in question the anticipated continuing rise in production and consumption of animal products is cause for concern. With their growth, it becomes harder by the day to tackle our climatic and other environmental challenges.

6.6 ...And finally, some research questions

This report has provided a general overview of the issues and come to some conclusions. But as we emphasise throughout, there are still many gaps in our understanding at multiple levels – from the highly specific to the systemic. This last sub-section of the report lists just some of the questions – by no means a comprehensive list – that merit further exploration.

Broadly speaking these questions fall into four categories. The first consists of quite specific questions that if addressed would fill some of the knowledge gaps this study has identified. The second set of questions are the 'parallel' research agendas – reviews on different and equally important topics relating to ruminants in grazing systems undertaken at a similar level to this one, as well as reviews of other systems of production for the monogastric as well as ruminant sector. Understanding here is needed to gain a fuller contextual picture of the role of ruminants in grazing systems. The third category is made up of 'what if?' explorations. The fourth category is itself one 'big' question: the one that ultimately needs answering and within which all the other questions sit.

6.6.1 Detailed questions that fill gaps identified in this study

- Can we identify specific contexts where grazing livestock help sequester carbon, such that the emissions in these systems partially or fully compensate for the CO_2, CH_4 and N_2O emissions they generate?
- Would it be possible to develop a check list that decision makers could use to identify these contexts and then to develop targeted policy frameworks that achieve absolute emission reductions in grazing systems?

- What research experiments are needed to obtain a better understanding of what grazing-for-sequestration might look like and what the trade-offs (for example as to other greenhouse gases, other environmental impacts or in relation to productivity or cost) might be?
- How might climate change alter conclusions as to the suitability of lands for grazing and the effects of grazing ruminants on the net GHG balance?

6.6.2 Parallel questions

Taking a similar approach to what was undertaken here with GHG emissions, what contestations and debates arise as to ruminants and:

- Biodiversity? (the subject of our next report)
- Hydrology and water functioning and use?
- Livelihoods, communities, jobs?
- Development and gender relations?
- Food security and human nutrition?
- Disease transmission? (Health at the interface between humans, animals and their environment).
- Good or bad animal welfare?

What does the evidence have to say about the 'goods' and 'bads' of grazing livestock in these respects? What trade-offs arise among these different areas of concern and how do they differ according to context?

Can we undertake similar inquiries for mixed crop-livestock systems; for intensive landless systems; and for the pig and poultry sectors?

Can we combine granularity with a systems perspective? Is it possible to identify ways of managing the trade-offs that arise in specific contexts while avoiding risks of indirect or rebound effects?

6.6.3 What ifs? And counterfactuals

- Can one identify possible alternative uses for resources currently used by livestock – including crop residues, agricultural by-products, food waste, feed grains and land?
- Could we model and explore alternative possible configurations of land and resource use and assess the implications for various aspects of the environment, for food security and nutrition, and for other aspects of societal concern?
- How would the costs and benefits play out differently in different parts of the world?

6.6.4 The big question

We conclude with the question identified in the preface to the report, which is this:

- In the context of planetary boundaries on the one hand and the need for human development (in its widest sense) on the other, what role – if any – do farmed animals play in a *sustainable* food system? If they do have a role, which systems and species are to be preferred, in which contexts, at what scale and at what level of overall production and consumption? How could the required changes happen?

Disclaimer
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