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Livestock, livelihoods and the environment: understanding the trade-offs

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Livestock are a global resource of significant benefits to society in the form of food, income, nutrients, employment, insurance, traction, clothing and others. In the process of providing these benefits, livestock can use a significant amount of land, nutrients, feed, water and other resources and generate 18% of anthropogenic global greenhouse gases. The total demand for livestock products might almost double by 2050, mostly in the developing world owing to increases in population density, urbanization and increased incomes. Multiple existing trade-offs and competing demands for natural resources will intensify, but reducing livestock product demand in places and capitalizing on the positive aspects of livestock systems such as the potential for sustainable intensification of mixed systems, the potential of ecosystems services payments in rangeland systems and well-regulated industrial livestock production might help achieve the goals of balancing livestock production, livelihoods and environmental protection.

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Introduction

Livestock, as part of global ecological and food production systems, are a key commodity for human well-being. Their importance in the provisioning of food, incomes, employment, nutrients and risk insurance to mankind is widely recognized [1,2].

Livestock systems, especially in developing countries, are changing rapidly in response to a variety of drivers. Globally, human population is expected to increase from around 6.5 billion today to 8.2 billion by 2050 [3]. More than 1 billion of this increase will occur in Africa. Rapid urbanization and increases in income are expected to continue in developing countries, and as a consequence the global demand for livestock products will continue to increase significantly in the coming decades.

Livestock systems have often been the subject of substantial public debate, because in the process of providing societal benefits, some systems use large quantities of natural resources and also emit significant amounts of greenhouse gases.

Considering that the demand for meat and milk is increasing, and that livestock is only one of many sectors that will need to grow to satisfy human demands, more trade-offs in the use of natural resources can be expected. This paper examines the key global trade-offs arising between livestock rearing, human well-being and environmental sustainability. These trade-offs not only have global consequences but also have local impacts on livelihoods and the environment. We use this information to formulate research questions that require significant attention to develop options for ensuring that livestock can continue to provide important livelihood benefits while improving the sustainability of agroecosystems.

Livestock—a key global commodity

Livestock systems occupy 45% of the global surface area [4] and are a significant global asset with a value of at least $1.4 trillion. Livestock industries are also a significant source of livelihoods globally. They are organized in long market chains that employ at least 1.3 billion people globally and directly support the livelihoods of 600 million poor smallholder farmers in the developing world [1,2]. Keeping livestock is an important risk reduction strategy for vulnerable communities, as animals can act as insurance when required. At the same time they are important providers of nutrients and traction for growing crops in smallholder systems [5]. Livestock are also an important source of nourishment. Livestock products contribute 17% to global kilocalorie consumption and 33% to protein consumption globally, but there are large differences between rich and poor countries [3].

Understanding and managing the demand for livestock products

Understanding and managing the demand for livestock products is essential for assessing the interrelationships and trade-offs arising between livestock systems, livelihoods and the environment.

Vast differences in the level of consumption of livestock products exist between rich and poor countries (Table 1).

Table 1

Projections of demand for livestock products in the developed and the developing world (adapted from Thornton and Herrero [7], data from Rosegrant *et al.* [3])

	Year	Annual per capita consumption		Total consumption	
		Meat (kg)	Milk (kg)	Meat (Mt)	Milk (Mt)
Developing	2002	28	44	137	222
	2050	44	78	326	585
Developed	2002	78	202	102	265
	2050	94	216	126	295

The level of consumption of milk and meat per capita in the developed world is higher than in the developing world but there is significant heterogeneity from country to country.

The demand for livestock products is rising rapidly in developing countries, mainly as a consequence of increased human population, urbanization and rapidly increasing incomes (see [6••,7] for reviews). Until 2002 the total consumption of animal products in both the developed and the developing world was roughly similar. However, recent projections [3] show that meat and milk total consumption in the developing world will be at least double than in the developed world by 2050, owing to the combination of the factors mentioned above. Even with this level of growth, the consumption of meat and milk per capita to 2050 in the developing world will still be less than half that in the developed world. These differences in consumption per capita partly explain why the environmental footprints of livestock products in the developing and the developed world differ by orders of magnitude [8].

The increased consumption of livestock products in the developing world has positive impacts on mortality and cognitive development of infants. On the contrary, the high level of consumption of animal products is also cited as a source of obesity, cancer, and heart problems in the developed world [9]. These somewhat opposing paradigms require a two-pronged approach. On the one hand we need to find strategies to reduce the demand of livestock products in the developed world, while on the other we need to sustainably intensify production to meet demand in the developing world.

Livestock production systems—different use of resources, different trade-offs

A heterogeneous array of livestock production systems satisfies the demand for animal products globally. Some of these systems are more important than others in different regions but several trends emerge and four simple categories of systems can be recognized: pastoral/agro-pastoral, mixed extensive systems, mixed intensive systems, and specialized/industrialized systems.

Globally, agro-pastoral and pastoral systems cover 45% of the earth's usable surface [4] and supply 24% of the global meat production [6••]. Projections by Bouwman *et al.* [51] show that in the next three decades 30% more grass will be required to meet the global demand for meat and milk and that improved management and use of fertilizers in parts of the world will be necessary to meet these increases. The environmental impacts of grazing systems intensification and the use of additional fertilizer inputs need to be carefully weighted against the potential increases in grassland productivity and animal production.

The developing world produces 50% of the beef, 41% of the milk, 72% of the lamb, 59% of the pork and 53% of the poultry globally [3,6••,10•]. These shares are likely to increase significantly to 2050 as rates of growth of livestock production in the developing world exceed those in developed countries (>2%/yr and <1%/yr, respectively) [3,10•]. Mixed extensive and intensive crop–livestock systems produce 65%, 75% and 55% of the bovine meat, milk and lamb, respectively, of the developing world share [10•]. This type of system is of particular importance from a food security and livelihoods perspective because over two-thirds of the human population live in these systems and apart from livestock products, they also produce close to 50% of the global cereal share [10•]. These are also the systems that are under the highest environmental pressures, particularly in high potential areas of Asia, where water tables and biodiversity are decreasing [3,10•], and in Africa where soil fertility is rapidly declining [5].

Industrial pork and poultry production account for 55% and 71% of global pork and poultry production, respectively [6••]. These systems will account for over 70% of the increases in meat production to 2030, especially in Latin America and Asia [6••,11]. However, large concentrations of animals are creating pollution problems and promoting transfers of nutrients and resources from ecologically vulnerable parts of the world. The demand for maize and coarse grains is projected to increase by 553 million tones by 2050 as a result of this monogastric expansion, and will account for nearly half of the grain produced in the period 2000–2050 [3].

While most production in the developed world is intensive and/or industrial, recent research [12] suggest that a shift towards integrated mixed farming systems in North America could still maintain high and profitable levels of production and at the same time have noticeable beneficial environmental impacts such as increased carbon sequestration, increased efficiency in use of resources, and recycling of nutrients, for example.

Research on mechanisms for de-intensifying these systems is an exciting new opportunity that requires further research to fully elucidate the impacts of these changes on food supply and environmental impacts.

Table 2 presents some of the key trade-off aspects and questions to consider when examining the linkages between livestock, livelihoods and the environment for each of these systems.

Livestock and land use change

Land inextricably links livestock to natural resource management. Livestock is not only the largest land use system on Earth, mainly in the form of pastoral systems that occupy up to 45% of the global land area [4], but also feed production, grazing, water and nutrient use, and biodiversity are largely dependent on land use and its potential change [13].

Different types of livestock systems have different impacts on land use and its change. Some of these impacts are direct and others indirect [4,6••] and are explained below.

Land use change and evolving livestock systems

Livestock systems are evolving at very fast rates, especially in the developing world [10•] and several theories of agricultural intensification and change exist to explain

Table 2

Main trade-offs between livestock, livelihoods and the environment

	Main trade-offs questions
General	Can we meet the demand for livestock products in an environmentally sustainable way or will the demand for livestock products be forced down as trade-offs for resources increase livestock product prices? Will reductions in demand for livestock products in the developed world lead to higher environmental sustainability? What will be the effects on producers? Can livestock product prices be maintained at low levels while accounting for the full environmental costs of livestock production? What will be the impacts on the poor? Will livestock systems intensification lead to more sustainable livestock benefits for society? Can the limits to sustainable intensification be adequately defined and indicators for measuring it developed and monitored in livestock systems?
Pastoral and agro-pastoral systems	Increased demand for livestock products presents a real potential for increasing incomes of livestock keepers but increases in extensive livestock production to meet demand fuel deforestation in the neotropics. Can this be reversed? A significant carbon sequestration potential exists in pastoral systems in Africa and Latin America but systems of payments for environmental services (measurements, monitoring, and payments) maybe too difficult to implement effectively. What are the alternatives? Pastoralists could participate of the economic benefits of livestock/wildlife co-existence but human population density, agricultural intensification are increasing rangeland fragmentation. Can this be reversed?
Mixed crop–livestock systems	Intensifying the diets of ruminants can decrease methane produced per unit of output, but can this be done without increasing demand for grains? Intensification of production may increase food production in parts of the developing world but it could also erode the diversity of animal and plant genetic resources as more productive animals and plants are sought. What is the best compromise? Africa: Sustainable intensification of mixed extensive areas possible but significant investment required in services, and markets. Can we target investments adequately? How do we increase productivity and incomes in these systems without significantly reducing soil fertility? Can the roles of livestock be re-defined? Asia: very high levels of production have been achieved but at the expense of significant reductions in the water tables in places. How to source feeds for ruminants in these systems will be a real challenge under more astringent irrigation levels. Mixed systems in North America gaining significant research interest but will these systems remain as productive and economically viable as their more industrialized counterparts?
Industrial systems	Large efficiency of conversion of output/unit of feed in the productivity of monogastrics is possible but dependence on concentrates will increases demands for feed grains that in turn fuel deforestation in the neotropics. What are alternative options? Demand for livestock products has significantly increased the production of chicken and pigs. This has reduced prices of meat for poor consumers but at the same time has caused pollution problems in places. Can we create easy regulatory framworks for environmental polution? Systems in North America and Europe are heavily subsidized to maintain certain environmental and landscape benefits but at the same time creating demand for feed (grains) and resources elsewhere thus fuelling deforestation. Is this sustainable? How do we account for these indirect effects?

this phenomenon. Several types of transition can be observed:

From pastoral to agro-pastoral systems This occurs, amongst others, as a result of pastoralists having to sedentarize owing to rangeland fragmentation and the need for social changes that demand income diversification and entry into the cash economy [14]. In some parts of the world this transition does not occur as land is not suitable for cropping and pastoralism remains the sole form of livelihoods system. How to reduce the risk and vulnerability of people and their assets while maintaining the ecological stability of these areas remains one of the important research areas on livestock, livelihoods and the environment.

From agro-pastoral systems to mixed crop/livestock systems of different degrees of intensification: This transition occurs mainly as a result of increased human population densities and associated increases in services and markets. In these systems, farm sizes usually decrease as population increases and loss of soil fertility (carbon and other nutrients) through the years in the absence of land for fallows significantly reduce soil carbon and subsequent farm productivity [15]. At the same time the role of livestock increases in the provision of manure for crops and cash flow from the sales of animal products. In places with good market access, these systems could sustainably intensify by replenishing nutrients from inorganic sources and promoting better regulated management practices and by creating market incentives to sell animal products.

In some cases, climate change is likely to reverse this transition, especially where losses in the length of growing period might reduce the possibility of cropping in marginal areas. Farmers might then have to revert to livestock rearing as the only viable livelihood system [52].

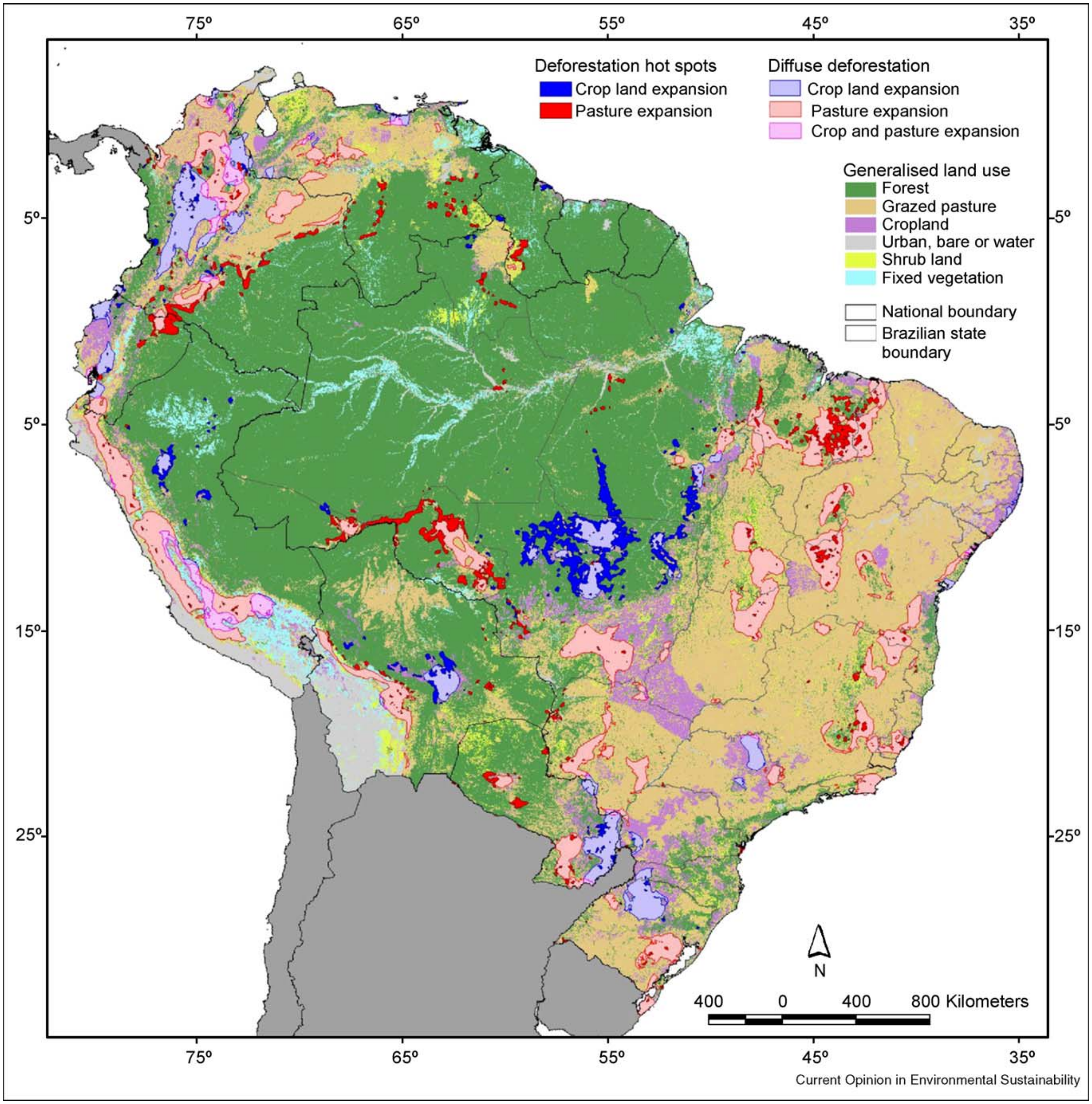
From mixed crop–livestock systems to specialized/industrial landless systems: This form of systems evolution is explained in detail by Naylor *et al.* [16]. Once market orientated smallholder production systems have intensified to significantly close yield gaps in crop and livestock production, increases in efficiency gains and opportunity costs for the land determine the viability of such enterprises. As a result farms tend to specialize, produce high value commodities, or shift towards industrial and landless systems where their dependence on labor and resources produced in surrounding areas becomes more limited. These systems, however, are dependent on resources elsewhere and transport of raw materials, imports of grains, and heavy nutrient loadings owing to large concentrations of animals [6••] become important issues. Some studies suggest that in places, these systems need to de-intensify and/or be regulated so as to ensure the viability of some ecosystems services, notably water [10•] and minimize deleterious impacts on human health. The combination of these systems is shaped significantly by agro-ecology, amongst other factors, which determines agricultural potential and makes certain systems predominate over others. A similar transition happened through Europe since the industrial revolution and is now the subject of significant environmental management [17].

The livestock and deforestation debate

The linkage between livestock and deforestation has been a topic of considerable research (see [18,19•]). The livestock and deforestation debate centers on two main phenomena related to different livestock production systems and their evolution. The first one is the direct conversion of forests into pastures for extensive cattle production, primarily in the neotropics [18]. According to several authors [18,19•,20,21] extensive cattle enterprises have been responsible for 65–80% of the deforestation of the Amazon (rate of forest loss of 18–24 million ha/yr). Some of these systems are changing and intensifying towards mixed crop/livestock systems and dairy production [20,22,23] as a result of new roads and markets and conversion of pastureland into cropland [18,21,22]. This is expected to reduce deforestation rates as farmers could increase efficiency and be able to obtain more product per unit of resource used [6••], though this view has been recently contested [20]. At the same time, forest is directly cleared for growing crops, like soybeans, mostly to feed pigs and poultry in industrial systems and to provide a high protein source for concentrates of dairy cattle (0.4–0.6 million ha/yr) [18,19•,21]. The rate of forest loss for crops is projected to increase as the demand for pig and poultry meat increases at faster rates than the consumption of red meats [6••,21]. The combined forest loss from cattle and feedstock production accounts for approximately 2.4 billion tones of CO_2 emissions worldwide [6••,24]. Figure 1 shows spatially the areas in South America that are likely to experience forest loss as a result of these phenomena.

Most soybeans are for export. This introduces the additional indirect effect of environmental impacts embedded in trade (in animal products or in resources for livestock production, in this case feeds) [6••,19•]. The EU and China are the biggest importers of soybeans from Brazil, and so their livestock industries need to be held accountable for a part of the CO_2 emissions from this deforestation. This is slowly occurring, as the EU applies trade regulatory frameworks and certification schemes for environmental compliance, but schemes have proven difficult to apply locally [19•]. Indirect effects and embedded CO_2 and methane emissions are aspects that are becoming more and more relevant as countries prepare to trade greenhouse gas emissions globally [24]. Several studies have also applied it to ecological footprints [8], water (virtual water [25]) and some nutrients, notably nitrogen [26], but this will eventually be applicable to a range of other resources.

Figure 1



Predicted deforestation hotspots in South America 2000–2010 (Wassenaar *et al.* [21]).

Livestock and nutrient cycles

The role of livestock in nutrient cycles has received a wealth of attention in the developed [26–28] and the developing world [29,30]. According to Sheldrick *et al.* [29], nutrients in manure as a proportion of total soil nutrient inputs account for 14% of Nitrogen, 25% Phosphorus and 40% of Potassium. However, there is large spatial heterogeneity depending on the type of system, resource endowment, crops planted, and soils, for example [30]. Livestock become more important as a source of soil nutrients in situations where reliance on fertilizer is low, like in SubSaharan Africa, as they are often the only source of carbon, nitrogen and other nutrients [26,30].

Cattle are the largest contributors to global manure production (60%), while pigs and poultry account for 9% and

10%, respectively. Recovery of nutrients from manure is highly variable and depends significantly on infrastructure and handling. Europe-wide analyses [28] show that approximately 65% of manure N is recovered from barns. Almost 30% of the N lost is during storage and maximum N cycling efficiencies (NCE) as N for crops was around 52%, though with large differences between member states. A large range of variation in NCE is also found in manure management systems in the developing world [30]. According to the Rufino *et al.* [30], manure handling and storage and synchrony of mineralization with crop uptake are key ways of increasing NCE in smallholder systems. This is a subject that still requires considerable research as animal numbers will increase to satisfy human demand for livestock products and therefore the importance of manures may also change. More attention will have to be paid as systems intensify as more manure could be beneficial in some systems, but the potential for increased leaching and contamination of water sources will also increase.

Livestock and water

The linkages between livestock and water use have not received as much attention as other aspects related to livestock and the environment. Recent analyses show that water use for livestock represent 31% (2180 km^3/yr) of the total water used for agriculture (7000 km^3/yr) [31]. This represents 840 km^3 transpired from grassland systems and 1340 km^3 for growing feeds. Scenarios of projections of water use have shown that if the demand for livestock products is to be met, water use from agriculture will need to almost double (13 500 km^3/yr), and this will be related to the increased needs for feed production throughout the world. Trade-offs with other sectors and competition of water will be significant in this case, especially with water for human consumption and industry. Water pollution, could increase as a result of additional intensification of production, especially in parts of developing countries, if unregulated [6••].

Significant variability exists in estimates of livestock water productivity (livestock benefits/water input [32]) from different livestock production systems and/or livestock products. The main source of variation is not the direct water consumption of animals (10%) but the water embedded in feed production (90%)[32]. This varies significantly dependent on location, type of system, feed resources available, diet diversity and intensification (grains vs forages vs crop residues), and level of production [32]. Hence, depending on the types of systems that predominate, different regions are associated with different proportions of the water used for feed production or for grazing [31]. In rangeland systems, water productivity can be significantly improved by rangeland management [33•]. According to some studies [33•], this source alone has the potential to reduce additional water use in agriculture by 45% by 2050. This possibility remains untapped and should be the source of significant research.

One of the biggest trade-offs in water use happens in irrigated crop–livestock systems with significant feed deficits during parts of the year when water has to be used for crops for direct human consumption rather than for green fodders. Currently 15% of evapotranspiration in these systems is associated with feed production [6••] but if demand for livestock products increases, the trade-off for irrigated water use between food and feed will increase. At the same time, there are several options to manage water productivity in these systems [32].

Water at present is considered a free or low-cost resource in most parts of the world [34]. This needs to be revisited for protecting this crucial ecosystem service. Water pricing is likely to play a key role as part of water management policies. It could improve water productivities as water would be used more sparingly, but it is necessary that water pricing policies do not affect the poor by limiting further their access to this resource. At the same time, paying ecosystems services payments to livestock farmers to protect water sources could also be part of the solution in certain places. Meeting the demand for livestock products under alternative water price scenarios is an area that also requires significant research.

Livestock and climate change

The linkages between livestock and climate change are two-way and dynamic. On the one hand, climate change has significant impacts on several aspects of livestock production such as feed quantity and quality, animal and rangeland biodiversity, distribution of diseases, management practices and production systems changes and others. Significant adaptation will need to occur in different production systems to cope with these changes. Readers are referred to recent reviews [35•,36–38] that deal with these aspects in detail. On the other hand, livestock have impacts on climate change through emissions of greenhouse gases.

Livestock contribute to 18% of global anthropogenic GHG emissions [6••]. The main sources and types of greenhouse gases from livestock systems are CO_2 from land use and its changes (feed production, deforestation) and N_2O from manure and slurry management that account for 32% and 31% of emissions from livestock, respectively. This is followed by methane production from ruminants, which accounts for 25% of emissions.

Large differences in GHG emissions exist between different regions. The climate change impacts of livestock production have been widely highlighted, particularly those associated with rapidly expanding industrial livestock operations in Asia and those linked to deforestation (feed production, pasture expansion) in Latin America.

However, livestock are not bad everywhere. In smallholder crop–livestock and agro-pastoral and pastoral livestock systems, livestock are one of a limited number of broad-based options to increase incomes and sustain the livelihoods of people who have a limited environmental footprint. GHG emissions from livestock and their impacts are relatively modest when compared with the contribution that livestock make to the livelihoods of hundreds of millions of poor people. This complex balancing act of resource use, GHG emissions and livelihoods requires better understanding. Weighting the environmental impacts vis-à-vis the social benefits is a subject that deserves significant new research, methodologies, and indicators to inform the debate more accurately. The same applies to the comparison of GHG emissions (total and per unit of output) between systems of different intensification level and between sectors. Life cycle and value chain analysis could play a significant role in this regard [39,40].

Mitigating greenhouse gases from livestock

Meeting the demand for livestock products in future carbon-constrained markets will require a mixture of adaptation and simple, effective and transparent mitigation strategies. According to Smith *et al.* [41] three different ways to contribute to reduction in GHG exist: direct reductions of GHG, removing CO_2 from the environment, and offsetting emissions through indirect effects. Livestock can contribute to these in the following ways.

Reducing GHG emitted by livestock systems

Managing the demand for livestock products: As mentioned before, managing the demand for livestock products in terms of reductions of consumption of livestock products in the developed world and sustainably intensifying systems in the developing world to produce more livestock products per unit of methane can be part of the solution. This needs to be accompanied by adequate regulations, incentives and policies [6••] and possible carbon quotas.*Intensification of the diets of animals*: This is an area that has enormous scope because a significant reduction in the amount of methane produced per unit animal product is possible by increasing the quality of the diets of ruminants [42]. This increased efficiency could be achieved through improved land use management with practices like improved pasture management (grazing rotation, fertilizer applications, development of fodder banks, improved pasture species, use of legumes, etc.) and supplementation with crop-by products and others. Other options include manipulation of rumen microflora, and use of feed additives [35•,41].

Control of animal numbers and shifts in breeds: animal numbers is possibly one of the biggest factors contributing directly to GHG emissions from livestock [43]. In the developing world, a large number of low-producing animals could be replaced by fewer but better fed animals of higher potential to be able to reduce total emissions while maintaining or increasing the supply of livestock products. These kinds of efficiency gains will be essential in carbon-constrained markets.*Shifts in livestock species*: switching species to better suit particular environments is a strategy that could yield higher productivity per animal for the resources available. At the same time, switches from ruminants to monogastrics could lead to the reduced methane emissions, though this could increase the demand for grains in places thus increasing CO_2 production from land use changes and N_2O from manure manangement. This trade-off needs to be closely assessed. Alternative feeds and feeding practices for monogastrics should be the subject of considerable research to reduce these trade-offs.

Reducing GHG from manure management: Reducing GHG from manures can be achieved through nutritional management [44] and better handling and storage of manure [28], for example. Reductions of 30% of emissions from manure could be obtained through existing technologies in Europe [28]. Regulations and incentives are also required to reduce N2O emissions from manures. These are of particular importance for managing excreta in the developing world and for slurry and manure applications in the developed world.

Livestock systems and carbon sequestration

Significant amounts of soil carbon could be stored in rangelands or in silvopastoral systems through a range of management practices suited to local conditions. This not only improves carbon sequestration but could also

Table 3

Potential for carbon sequestration (Tg C/yr) in global rangelands of different overgrazing severity, by Continent (Conant and Paustian [45••])

	Light	Moderate	Strong	Extreme	Total
Africa	1.9	8.6	6.1	0.1	16.7
Australia/Pacific	4.5	−0.1	0.0		4.4
Eurasia	0.8	3.2		0.3	4.3
North America	0	1.6	0.6		2.2
South America	6.1	11.3	0.7	0.4	18.1
Total	13.3	24.4	7.4		45.7

turn into an important diversification option for sustaining livelihoods of smallholders and pastoralists through payments for ecosystems services. The potential for carbon sequestration from global degraded rangelands is approximately 45 Tg C/yr, with the highest potentials in Africa and Latin America (37% and 40% of potential global rangeland C sequestration, respectively) [45••] (Table 3). Average rates of C sequestration is this study were 0.18 Mg C/ha/yr [45••].

While technical options for mitigating emissions from livestock in developing countries exist, there are various problems to be overcome, related to incentive systems, institutional linkages, policy reforms, monitoring techniques for carbon stocks, and appropriate verification protocols, for example. For the pastoral lands, Reid *et al.* [46] conclude that mitigation activities have the greatest chance of success if they build on traditional pastoral institutions and knowledge, while providing pastoralists with food security benefits at the same time.

Livestock systems and GHG emission offsets

Crops and residues from agricultural lands can be used as a source of fuel, either directly or after conversion to fuels such as ethanol or diesel. While these bio-energy feedstocks still release CO_2 upon combustion, the carbon is of recent atmospheric origin (via photosynthesis), rather than from fossil carbon. The net benefit of these bio-energy sources to the atmosphere is equal to the fossil-derived emissions displaced, less any emissions from producing, transporting, and processing. CO_2 emissions can also be avoided by agricultural management practices that forestall the cultivation of new lands now under forest, grassland, or other non-agricultural vegetation [41]. At the same time, biogas from manures can be used to offset energy use in livestock systems.

Livestock and biodiversity

Livestock have widespread direct and indirect impacts on biodiversity, which is defined as the number and diversity of genes, species, populations, and ecosystems. These impacts are principally negative, although there are some positive impacts as well, and they affect every square km of Earth—on land, in the sea, and throughout the atmosphere. Overall, biodiversity loss through livestock is driven by the increasing demand and consumption of milk, meat, and eggs, which leads to a greater need to grow crops and harvest fish to feed livestock [6••]. Livestock negatively affect biodiversity through heavy grazing on plants and soil compaction; forest loss when pastures and cropland expand to grow livestock feed in the tropics [19•], often driven by long-distance trade in feeds; emissions of greenhouse gases that cause climate change and then affect biodiversity; diseases spread by livestock to wildlife; simplification of landscapes through intensification and fragmentation [14]; competition of livestock with wildlife; pollution of watercourses with nutrients, drugs, and sediments, with related effects on aquatic biodiversity; native biodiversity loss through competition with non-native feed plants; and overfishing to create fishmeal for livestock [47•]. Positive impacts occur when livestock production is more efficient, where fewer natural resources are used for each kilogram of milk, meat, or eggs produced [48]; moderate grazing increases species diversity; and pastoral land use protects wildlife biodiversity in savannah landscapes [49].

While livestock have many direct impacts on biodiversity through trampling, grazing, and defecation, the larger impacts may be indirect—through deforestation to create pastures; emissions of methane and other greenhouse gases; the growing feed trade; and the pollution of streams, rivers, lakes, and oceans [47•]. Effects on marine systems are multiple and unexpected [50], through fish harvest for fishmeal, coral loss through climate change, introduction of marine invasion species, and probably dust-transmitting pathogens reaching coral reefs.

Conclusions

There is a large body of evidence that suggests that livestock and environmental trade-offs are currently substantial and that these will increase significantly in the future as a result of the increased demand for livestock products from the growing population. Some of the most important impacts are those associated with land use change for feed production both for ruminants and monogastrics, which have significant simultaneous impacts on a range of environmental dimensions (land use, GHG, water cycles, nutrient balances, biodiversity).

At the same time, there seem to be significant opportunities in livestock systems for improving environmental management while improving the livelihoods of poor people. Sustainable intensification of smallholder systems could offer promising alternatives in highly populated areas of the developing world, while there is strong evidence that rangelands can sequester significant amounts of carbon and can play an important role in improving the water productivity of whole ecosystems in certain places. These strategies, though potentially difficult to implement, require substantial research to verify their feasibility.

There is a need for a fundamental shift in the way we see demand for livestock products and in the way different production systems can respond to meet this demand. Demand for livestock products needs to be reduced in places where there is excessive consumption of animal products or in places where environmental impacts are currently or potentially severe. At the same time, there is a need to simultaneously de-intensify certain systems through policies and payments for ecosystems services, while other systems that might have been neglected in the past intensify via technologies that can improve efficiency gains to produce more product per unit of resource. We need to provide significant incentives so that the marginal rangeland areas often rich in biodiversity can be protected and farmers can benefit from these. There is a subtle balancing act for achieving this and it needs commitment from the science community, policy makers and other stakeholders if livestock are going to continue having a significant role in the livelihoods of millions of people around the world.

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• of special interest
•• of outstanding interest

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