COMMENTARY:

Ruminants, climate change and climate policy

William J. Ripple, Pete Smith, Helmut Haberl, Stephen A. Montzka, Clive McAlpine and Douglas H. Boucher

Greenhouse gas emissions from ruminant meat production are significant. Reductions in global ruminant numbers could make a substantial contribution to climate change mitigation goals and yield important social and environmental co-benefits.

Although a main focus of climate policy has been to reduce fossil fuel consumption, large cuts in CO_2 emissions alone will not abate climate change. At present non-CO_2 greenhouse gases contribute about a third of total anthropogenic CO_2 equivalent (CO_2e) emissions and 35–45% of climate forcing (the change in radiant energy retained by Earth owing to emissions of long-lived greenhouse gases) resulting from those emissions[1] (Fig. 1a). Only with large simultaneous reductions in CO_2 and non-CO_2 emissions will direct radiative forcing be reduced during this century (Fig. 1b). Methane (CH_4) is the most abundant non-CO_2 greenhouse gas and because it has a much shorter atmospheric lifetime (~9 years) than CO_2 it holds the potential for more rapid reductions in radiative forcing than would be possible by controlling emissions of CO_2 alone.

There are several important anthropogenic sources of CH_4: ruminants, the fossil fuel industry, landfills, biomass burning and rice production (Fig. 1c). We focus on ruminants for four reasons. First, ruminant production is the largest source of anthropogenic CH_4 emissions (Fig. 1c) and globally occupies more area than any other land use. Second, the relative neglect of this greenhouse gas source suggests that awareness of its importance is inappropriately low. Third, reductions in ruminant numbers and ruminant meat production would simultaneously benefit global food security, human health and environmental conservation. Finally, with political will, decreases in worldwide ruminant populations could potentially be accomplished quickly and relatively inexpensively.

Ruminant animals consist of both native and domesticated herbivores that consume plants and digest them through the process of enteric fermentation in a multichambered stomach. Methane is produced as a by-product of microbial digestive processes in the rumen. Non-ruminants or 'monogastric' animals such as pigs and poultry have a single-chambered stomach to digest food, and their methane emissions are negligible in comparison. There are no available estimates of the number of wild ruminants, but it is likely that domestic ruminants greatly outnumber the wild population, with a reported 3.6 billion domestic ruminants on Earth in 2011 (1.4 billon cattle, 1.1 billion sheep, 0.9 billion goats and 0.2 billon buffalo)[2]. On average, 25 million domestic ruminants have been added to the planet each year (2 million per month)[2] over the past 50 years (Fig. 1d).

Worldwide, the livestock sector is responsible for approximately 14.5% of all anthropogenic greenhouse gas emissions[3] (7.1 of 49 Gt CO_2e yr^{-1}). Approximately 44% (3.1 Gt CO_2e yr^{-1}) of the livestock sector's emissions are in the form of CH_4 from enteric fermentation, manure and rice feed, with the remaining portions almost equally shared between CO_2 (27%, 2 Gt CO_2e yr^{-1}) from land-use change and fossil fuel use, and nitrous oxide (N_2O) (29%, 2 Gt CO_2e yr^{-1}) from fertilizer applied to feed-crop fields and manure[3]. Ruminants contribute significantly more (5.7 Gt CO_2e yr^{-1}) to greenhouse gas emissions than monogastric livestock (1.4 Gt CO_2e yr^{-1}), and emissions due to cattle (4.6 Gt CO_2e yr^{-1}) are substantially higher than those from buffalo (0.6 Gt CO_2e yr^{-1}) or sheep and goats (0.5 Gt CO_2e yr^{-1})[3]. Globally, ruminants contribute 11.6% and cattle 9.4% of all greenhouse gas emissions from anthropogenic sources. The total area dedicated to grazing encompasses 26% of the terrestrial surface of the planet[4]. Livestock production accounts for 70% of global agricultural land and the area dedicated to feed-crop production represents 33% of total arable land[4]. The feeding of crops to livestock is in direct competition with producing crops for human consumption (food security) and climate mitigation (bioenergy production or carbon sequestration)[5].

Deforestation has been responsible for a significant proportion of global greenhouse gas emissions from the livestock sector and takes place mostly in tropical areas, where expansion of pasture and arable land for animal feed crops occurs primarily at the expense of native forests[4,6]. Lower demand for ruminant meat would therefore reduce a significant driver of tropical deforestation and associated burning and black carbon emissions. The accompanying reduction in grazing intensity could also allow regrowth of forests and other natural vegetation, resulting in additional carbon sequestration in both biomass and soils with beneficial climate feedbacks[5,6].

Lower global ruminant numbers would have simultaneous benefits for other systems and processes. For example, in some grassland and savannah ecosystems, domestic ruminant grazing contributes to land degradation through desertification and reduced soil organic carbon[5]. Ruminant agriculture can also have negative impacts on water quality and availability, hydrology and riparian ecosystems[4,7]. Ruminant production can erode biodiversity through a wide range of processes such as forest loss and degradation, land-use intensification, exotic plant invasions, soil erosion, persecution of large predators and competition with wildlife for resources[4–7].

Ruminant production also has implications for food security and human health. Roughly one in eight people in the world are severely malnourished or lack access to food owing to poverty and high food prices[2]. With over 800 million people chronically hungry, we argue that the use of highly productive croplands to produce animal feed is questionable on moral grounds because this contributes to exhausting the world's food supply. Conversely, ruminant agriculture will remain important in pastoral or subsistence situations where ruminants can provide a source of food from landscapes that cannot be used to practicably sustain crops (for example, grasslands). For these regions, particularly in developing countries, ruminants represent a stock that can buffer against times of bad harvest or other detrimental fluctuations.

In developed countries, high levels of meat consumption rates are strongly correlated with rates of diseases such as obesity, diabetes, some common cancers and heart disease[8,9]. Moreover, reducing meat consumption and increasing the proportion of dietary protein obtained from high-protein plant foods — such as soy, pulses, cereals and tubers — is associated with significant human health benefits[8,9].

Although policymakers strive to reduce fossil fuel emissions, the livestock sector has generally been exempt from climate policies and little is being done to alter patterns of production and consumption of ruminant meat products[5,10]. Annual meat production worldwide is growing rapidly, and without policy changes is projected to more than double from 229 million tonnes in 2000 to 465 million tonnes in 2050[4]. The greenhouse gas footprint of consuming ruminant meat is, on average, 19–48 times higher than that of high-protein foods obtained from plants (Fig. 2), when full life cycle analysis including both direct and indirect environmental effects from 'farm to fork' for enteric fermentation, manure, feed, fertilizer, processing, transportation and land-use change are considered. Non-ruminant meats such as those from pigs and poultry (and marine fisheries) have a lower carbon equivalent footprint, although they still average 3–10 times greater than high-protein plant foods (Fig. 2). Pigs and poultry also consume feed that could otherwise be more efficiently consumed directly by humans.

Moving forwards, there are steps that governments and international climate negotiators can take to curb global ruminant increases and reduce emissions from the agricultural sector. Reducing meat consumption as a demand-side mitigation action offers greater greenhouse gas reduction potential (0.7–7.3 Gt CO_2e yr^{-1}) than the supply-side measures of increased crop yields (0.2–1.9 Gt CO_2e yr^{-1}) or livestock feeding efficiency (0.2–1.6 Gt CO_2e yr^{-1}) (Table 2 in ref. 5). In terms of short-term climate change mitigation during the next few decades, if all the land used for ruminant livestock production were instead converted to grow natural vegetation, increased CO_2 sequestration on the order of 30–470% of the greenhouse gas emissions associated with food production could be expected[5,11]. Nonetheless, policies targeting both supply-side measures to improve agricultural production efficiencies and demand-side mitigation for encouraging behavioural changes to reduce meat consumption (particularly ruminant meat) and waste have the best chance of providing rapid and lasting climate benefits[5]. Influencing human behaviour is one of the most challenging aspects of any large-scale policy, and it is unlikely that a large-scale dietary change will happen voluntarily without incentives[12]. Implementing a tax or emission trading scheme on livestock's greenhouse gas emissions could be an economically sound policy that would modify consumer prices and affect consumption patterns[12]. A tax has recently been successfully modelled for the European Union with tax rates proportional to the average greenhouse gas emissions per unit of food sold[10], although social justice, equity and food access issues need to be carefully considered. Such demand-side mitigation measures have more social and environmental co-benefits than supply-side measures[5].

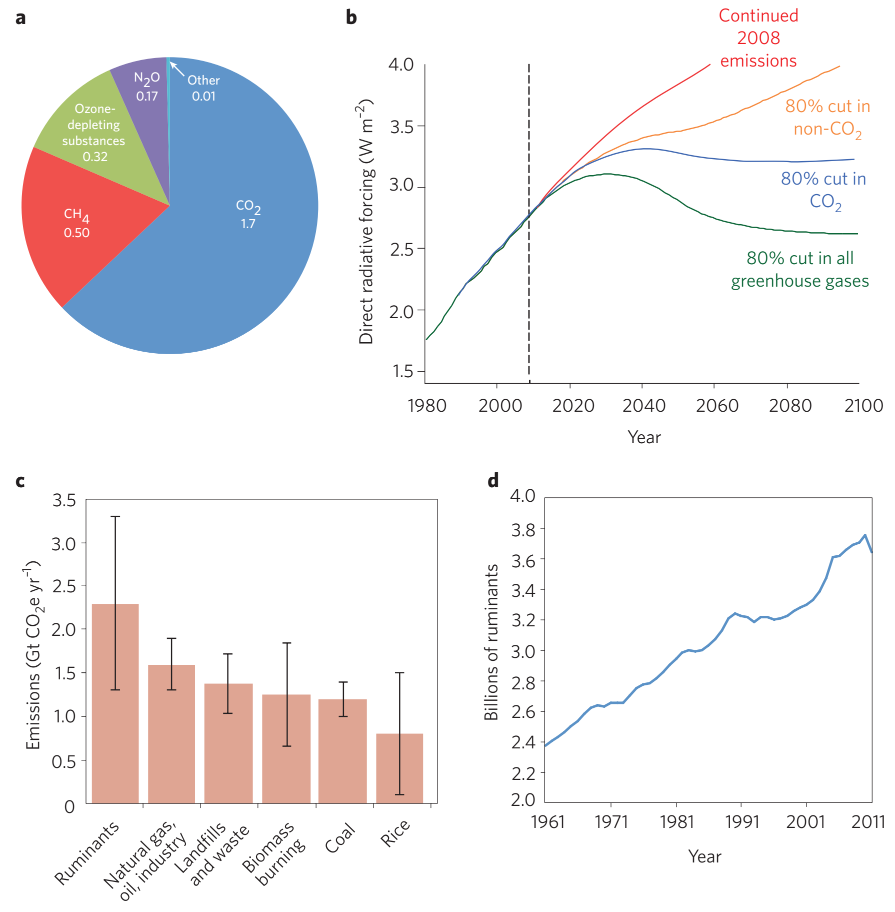

Figure 1 | Compound- and sector-specific emissions of greenhouse gases, associated radiative forcing and global ruminant numbers over the past 50 years. **a**, Estimates of direct radiative forcing in 2008 for CO_2 and non-CO_2 greenhouse gases from anthropogenic sources. **b**, Projections of radiative forcing in four different scenarios: constant future emissions at 2008 levels (red); 80% reduction in only non-CO_2 emissions (orange), 80% reduction in only CO_2 emissions (blue), and 80% reductions in both non-CO_2 and CO_2 emissions (green). **c**, Estimated annual anthropogenic emissions from major sources of methane in recent years. Error bars represent 1 standard deviation. **d**, Global ruminant numbers from 1961 to 2011. Data for **a**–**c** from ref. 1, **d** from ref. 2.

International climate negotiators can take steps to reduce greenhouse gas emissions from livestock as well as from the burning of fossil fuels. So far, global climate policy instruments have mainly focused on engineering improved industrial processes, energy efficiency and investments in alternative energy generation technologies, because sustainability has been predominantly interpreted as technological progress rather than changed patterns of human behaviour[6]. Continued growth of ruminant meat consumption will represent a major obstacle for reaching ambitious climate change targets. The substantial environmental and climate costs of increased meat consumption have been recognized by the United Nations Food and Agriculture Organization[4]. However, mitigation of greenhouse gas emissions from ruminants has not received adequate attention in negotiations under the United Nations Framework Convention on Climate Change[13]. Meeting documents show that activities to reduce emissions from ruminants and agriculture in general, and in negotiations on land use, land-use change and forestry and reducing emission from deforestation and forest degradation have been disproportionately slow[13]. The land-use accounting under the Kyoto Protocol provides insufficient coverage of land-based emissions considering their large contributions to greenhouse gas fluxes. The Kyoto Protocol also only covers industrialized countries, so it misses some of the largest emerging ruminant producers. Further, under Articles 3.3 and 3.4 of the Kyoto Protocol, emission reduction commitments for cropland and grazing land management are optional in many situations[14].

The above-presented evidence calls for a more comprehensive approach to accounting in the Agriculture, Forestry and Other Land Use sector, following the lead of those countries requesting mandatory accounting for land-based emissions, including cropland and grazing land sectors[14]. Progress would be facilitated if emissions resulting from ruminant livestock production are placed on the agenda of forthcoming global climate meetings such as the annual sessions of the Conference of the Parties. Current national policies on mitigating climate change could also be revised to curtail emissions from ruminant livestock in both developed and developing countries.

Because the Earth's climate may be near tipping points to major change, the need to act is increasingly pressing[15,16]. Lowering peak climate forcing quickly with ruminant and CH_4 reductions would lessen the likelihood of irreversibly crossing such tipping points into a new climatic state[1]. Reducing the numbers of ruminants will be a difficult and complex task, both politically and socially. However, decreasing ruminants should be considered alongside our grand challenge of significantly reducing the world's reliance on fossil fuel combustion. Only with the recognition of the urgency of this issue and the political will to commit resources to comprehensively mitigate both CO_2 and non-CO_2 greenhouse gas emissions will meaningful progress be made on climate change. For an effective and rapid response, we need to increase awareness among the public and policymakers that what we choose to eat has important consequences for climate change. ❐

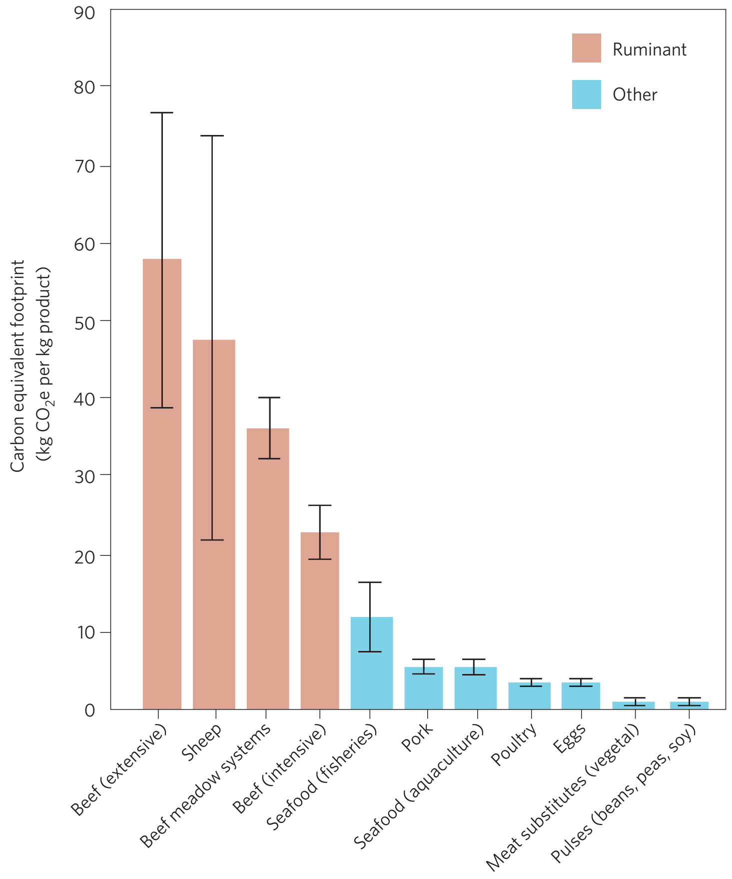

Figure 2 | Average carbon equivalent footprint of protein-rich solid foods per kilogram of product from a global meta-analysis of life-cycle assessment studies. Extensive beef involves cattle grazing across large pastoral systems, whereas intensive beef typically involves feedlots. Meat substitutes are also known as meat analogues, which are high-protein plant products that have aesthetic qualities (such as flavour, texture, appearance) of specific types of meat. Error bars represent standard errors. Data from ref. 17.

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References

1. Montzka, S. A., Dlugokencky, E. J. & Butler, J. H. *Nature* **476,** 43–50 (2011).
2. *FAOSTAT* (FAO, accessed 12 August 2013); http://go.nature.com/Z23f7E
3. Gerber, P. J. *et al. Tackling Climate Change Through Livestock — A Global Assessment of Emissions and Mitigation Opportunities* (FAO, 2013).
4. Steinfeld, H. *et al. Livestock's Long Shadow: Environmental Issues and Options* (FAO, 2006).

5. Smith, P. *et al. Glob. Change Biol.* **19,** 2285–2302 (2013).
6. McAlpine, C. A., Etter, A., Fearnside, P. M., Seabrook, L. & Lawrence, W. F. *Glob. Environ. Change.* **19,** 21–33 (2009).
7. Beschta, R. L. *et al. Environ. Manage.* **51,** 474–491(2012).
8. American Dietetic Association *J. Am. Dietetic Assoc.* **109,** 1266–1282 (2009).
9. Fraser, G. E. *Am. J. Clin. Nutr.* **89**(supplement), 1607S–1612S (2009).
10. Wirsenius, S., Hedenus, F. & Mohlin, K. *Climatic Change* **108,** 159–184 (2011).
11. Schmidinger, K. & Stehfest, E. *Int. J. Life Cycle Assess.* **7,** 962–972 (2012).
12. Popp, A. *et al. Glob. Environ. Change* **20,** 451–462 (2010).
13. http://unfccc.int
14. *Views on Land Use, Land-use Change and Forestry Issues Referred to in Decision 2/CMP.7, Paragraphs 5-7. Submissions from Parties and Admitted Observer Organizations* 12–18 (SBSTA, UNFCCC, 2013); http://go.nature.com/hLAtTN
15. Lenton, T. M. *Ambio* **41,** 10–22 (2012).
16. Whiteman, G., Hope, C. & Wadhams, P. *Nature* **499,** 401–403 (2013).
17. Nijdam, D., Rood, T. & Westhoek, H. *Food Policy* **37,** 760–770 (2012).

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COMMENTARY:

Social learning and sustainable development

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To understand what social learning approaches can offer the sciences of adaptation and mitigation, we need to assemble an appropriate evidence base.

Research-for-development institutions such as the Food and Agriculture Organization (FAO) of the UN, CGIAR and their partners are under mounting external pressure from donors to link knowledge to actions that achieve substantive, long-lasting and demonstrable development outcomes[1]. If research is genuinely to result in beneficial changes in behaviour, policies and institutions, research outputs need to be much better informed by and engaged with the processes through which individuals, communities and societies learn and adapt their behaviour in the face of change[2,3]. Social learning approaches may be able to contribute substantially to this aim[4]. Definitions vary, but in a nutshell social learning approaches facilitate knowledge sharing, joint learning and knowledge co-creation between diverse stakeholders around a shared purpose, taking learning and behavioural change beyond the individual to networks and systems. Through an iterative process of working together — engaged in interactive dialogue, exchange, learning, action, reflection and continuing partnership — new shared ways of gaining knowledge emerge that lead to changes in practice[5]. As such, social learning builds on well-established traditions from participatory development, but puts learning and collective change at the centre of engagement. Social learning can provide a way to address complex socio-ecological (so-called wicked) problems by integrating diverse knowledge and value systems at many different levels and through different learning cycles.

From theory to practice

As a concept, social learning is appealing. But how can we implement it as effectively and efficiently as possible? In practice, it takes many different forms and can be used to effect different types of change. Some examples of innovative sustainable agricultural development projects and programmes that are taking this approach are shown in Table 1. These illustrate a range of scales at which social learning and change are happening, from the individual to the community to networks and systems. The range of outcomes from these projects is equally wide, from changes in the way farmers go about their business to new agricultural input distribution systems to the creation of new institutions and the empowerment of national agricultural planners.

On the face of it, social learning approaches should be able to contribute to smarter, more effective research-for-development institutions in terms of performance and governance, and also help them to achieve more sustainable results, measured as development outcomes[6]. We also know that iterative learning processes are perceived to be a critical component of adapting to environmental change, and that there is an absence of learning tools that can be applied in contexts where uncertainty is high[7]. But at the moment, we have only limited evidence on the impact of social learning approaches on tangible development outcomes, and not much is known about the costs of social learning approaches in comparison with more traditional, linear practices[8]. There has been only limited effort put into evaluating social learning methods beyond one-off case studies and *post hoc* or appreciative reflections[9,10]. Larger-scale reviews of social learning have thus far focused on its framings and methodologies more than on its ultimate impacts. Scientists are particularly concerned with the transaction costs that they perceive to be high (for example, the amount of time spent dealing with 'messy partnerships') and a limited ability to replicate and scale up results more broadly.

A framework for gathering evidence

In view of the limitations of the current evidence base and calls for greater empirical rigour in evaluating social learning[11], we are embarking on a systematic evidence-gathering effort, using a common evaluative framework to track new initiatives from