Intensifying pastoralism may not reduce greenhouse gas emissions : wildlife-dominated landscape scenarios as a baseline in life cycle analysis

Manzano, Pablo

2019-02-21

Manzano , P & White , S R 2019 , ' Intensifying pastoralism may not reduce greenhouse gas emissions : wildlife-dominated landscape scenarios as a baseline in life cycle analysis ' , Climate Research , vol. 77 , no. 2 , pp. 91-97 . https://doi.org/10.3354/cr01555

http://hdl.handle.net/10138/326549
https://doi.org/10.3354/cr01555

Title: Greenhouse gas emissions from pastoral livestock systems versus alternative land-management scenarios

Short title: Alternative livestock emission scenarios

Authors: P. Manzano[1 2]*, S. R. White[3 4]

Affiliations:

[1]Commission on Ecosystem Management, International Union for Conservation of Nature, P.O. Box 68200 – 00100 Nairobi, Kenya

[2]Asociación Biomas, 28028 Madrid, Spain

[3]Alberta Biodiversity Monitoring Institute, CW 405 Biological Sciences Building, University of Alberta, Edmonton, AB T6G 2E9, Canada

[4] InnoTech Alberta, 250 Karl Clark Road, Edmonton, AB T6N 1E4, Canada

*pablo.manzano.baena@gmail.com

Abstract

The general public is increasingly critical of extensive, ruminant-dominated systems for their attributed high GHG emissions. However, advocates of low input, grass-fed systems present them as paradigmatic sustainable production systems because of their biodiversity, land use, rural development and animal welfare benefits. We reconcile both analyses by proposing to assess baseline emissions in grazed ecosystems. We show that policies aiming at transitioning grass-fed systems towards fodder-based (concentrate- or grain-based) systems can be ineffective at reducing emissions because wild ruminants or termites fill livestock's ecological niche. Climate change policies targeting livestock should carefully evaluate derived emissions scenarios.

Key words

GHG emissions, livestock, climate policy, emission scenarios, rangelands, wild herbivores

Main text

The contribution of ruminant livestock to climate change has been a recurring issue in the recent public debate. The urge to act against climate change (Nature Climate Change editorial 2017), and the development of a multinational agreement to do so at the CoP21 meeting in Paris, has raised multiple voices in the media (The Economist 2014, Wellesley 2015, Monbiot 2017) calling for interventions in the livestock sector. The underlying reasons are twofold: first, 14.5%, of annual total anthropogenic GHG emissions is attributed to livestock. Second, meat consumption and income follow an inverted U-shaped relationship that forecasts a huge increase in animal product demand from China, India and other developing countries (Gerber et al 2013), as their societies increase in affluence. Alternative protein sources are also being advocated for, including insects (Heffernan 2017) or vegan diets (Poore & Nemecek 2018).

These views are not new, but were strengthened following the airing of the environmental documentary "Cowspiracy" in 2015, which accused environmental organizations of ignoring the livestock industry's role in climate change. This was echoed by the media, calling for the intensification of livestock production as a climate-friendly strategy, in response to the high amount of emission equivalents attributed to ruminant methanogenesis.

As such calls for livestock policy change have particularly negative repercussions for pastoralist systems, advocates for grass-fed systems have responded with arguments around the capacity of rangelands to fix carbon and the compensation it would imply in terms of GHG effect. However, such arguments have been contested by more comprehensive data analyses (Garnett et al 2017). Analyses of the consequences of suggested policy applications, however, have still failed to integrate pertinent research.

Life cycle analysis (LCA) has been used to attribute GHG emission to a host of products, and to specific hotspots within the supply chain (Gerber et al 2013, Wible et al 2014, Poore & Nemecek 2018). LCA of livestock products, which includes emissions from fodder production, has revealed the role of fossil fuels in livestock production accounts for only 20%, while methane from enteric fermentation and nitrogen oxides from manure – mainly from ruminants – and, to a lesser extent, nitrogen oxides from non-ruminant manure and fodder fertilizers, account for most emissions. The low average quality of feed in developing countries and marginal areas (mountains, drylands) around the world, based on grass-rich diets with high cellulose and lignin content and very minimal concentrate- and grain-based inputs, is the main underlying GHG source and also the most obvious target for action. This is to be achieved through farm intensification: by improving feed conversion rates through higher protein content that shortens days to slaughter, and through promotion of meat sources that are less emission-intensive, such as chicken and pig (Gerber et al 2013, Garnett 2017, Wirsenius & Hedenus 2017), for ruminants are blamed for 80% of the GHG emissions in livestock systems, or 65% for cattle alone (Garnett et al 2017). LCA has proven to exert great influence on how society at large, and industry stakeholders in particular, perceive sustainability (Garnett 2014, Wirsenius & Hedenus 2107); livestock production seems to be no exception. Scientists are further expanding the recommendation for livestock intensification (Havlík et al 2014, Ripple et al 2014, Merrigan et al 2015), which is being echoed in media discussions (The Economist 2014, Wellesley 2015, Monbiot 2017) that lead to policy agendas (Manzano Baena 2012). 'Land sparing' strategies are expected to also help by concentrating livestock in intensive farms and releasing land from grazing pressure, i.e. abandoning it (Campbell et al 2014, Balmford et al 2018).

The lifespans of the different GHGs vary; nitrous oxide and methane, the primary GHGs produced in livestock production, have lifespans on the range of decades, whereas the impact of CO_2 spans millenia. Newer, alternative assessment methodologies that take into account the varied durations of GHGs in the atmosphere do offer a more environmentally sustainable picture for extensive livestock (Pierrehumbert & Eshel 2015). Studies in tropical Africa show an emission profile for pastoralist systems lower than originally estimated (Pelster et al 2016, Assouma et al 2017). However, the view of extensive livestock's high GHG profile is sustained, with increased new evidence pointing to an even more relevant role (Wolf et al 2017), as are subsequent urgings to replace beef with pork and poultry (Garnett et al 2017) or with vegan diets (Poore & Nemecek 2018).

Implementation of the proposed policy measures will inevitably target widely extended production systems that rely on vast expanses of marginal land unsuitable for crop production: mainly low input, low output livestock systems. These systems can be broadly referred to using the umbrella term "pastoralism", encompassing systems not typically labeled as such, including those of many North American producers. This is a generalized term for systems that actually have a varying degree of inputs, such as occasional fodder provision or fertilizer applications; we propose a conceptual analysis addressing systems where they are lowest. In such systems, the majority of feed resources would consist of rangelands – including forests, woodlands and grasslands – that are natural ecosystems, and not deforested lands, e.g. Amazonian pastures. These rangelands are generally characterized by high variation in production and quality across seasons and years, and very high fiber content. Efficiency in their use increases with livestock mobility or communal tenure that allows for the use of heterogeneous landscapes and resources, and eliminates concentrate- and grain-based input, and confinement periods.

How common are these systems globally? If analyzed isolated, grass-fed systems on grasslands account for a maximum of 49% of the continental land, and host almost a fifth of the cattle and a third of the small ruminants (Garnett et al 2017). Such approaches do, however, not take into account that many pastoralist systems make use of wood pastures (Plieninger et al 2015) or fodder trees (Franzei et al 2014), or the relevance in terms of area use of livestock species with reduced numbers such as reindeer, yaks or camels, so the extent of such systems may be significantly larger (Manzano 2015), up to 56% of the global land mass (Sayre 2017). In any case, and in spite of the uncertainties of the total extension of grazed areas, uncultivated grass and leaves make up 46% of the global livestock feed intake (Mottet et al 2017). These figures are of course higher for ruminants or for grazed and mixed systems, the latter being more relevant in terms of global livestock numbers and production (Garnett et al 2017), which highlights the relevance of the perspective we present here.

Pastoralist systems also generally have advantages regarding sustainability and efficiency, including the use of marginal lands that do not compete with agriculture – especially important in regard to 'land sparing' arguments; improved aspects of animal welfare; higher product quality; nutrient cycling and soil improvement; and social justice for farmers that cannot afford to purchase fodder (Bernués 2017, Manzano-Baena & Salguero-Herrera 2018). Pastoralist systems also generally have high environmental benefits, although there is variability depending on grazing practices and historical land cover. These benefits include improved ecosystem function, ecosystem services provision, and biodiversity conservation in comparison with abandoned landscapes, very much in contrast with other agricultural practices (Eisler et al 2014, Schader et al 2015, Bernués 2017, Muller et al 2017). Indeed, modern day grazing practices can in many ways emulate the impact of historical herbivores, achieving a similar function (Veblen et al 2016).

These benefits have been incorporated in LCA, showing a more favorable picture for pastoralism, yet with continued implications of high GHG emissions (Ripoll-Bosch et al 2013, Bernués 2017). A modeled assessment (White & Hall 2017) of a total switch to plant-based diets in the United States shows clear benefits in terms of GHG emissions, but at the expense of higher land conversion, unbalanced diets and a higher risk not to meet the population's nutritional requirements. High GHG emission intensities attributed to pastoralism are consequently interpreted in the public debate as a burden to be borne in exchange for services provided by benefits associated with pastoralists. Future policy scenarios promoting monogastrics, land sparing, or changes in food ratio composition, would correctly apply the philosophy of sustainable intensification, correctly targeting mixed crop-livestock systems to reduce GHG emission intensity (Gerber et al 2013, Herrero et al 2016, Wirsenius & Hedenus 2017). However, they could collaterally eliminate pastoral systems in conjunction with other negative policies that are already undermining them (de Jode 2010, Khazanov 2013, Manzano 2015, Bassi 2017), leading us to the key question: would total GHG emissions in pastoral lands indeed be reduced?

Quantification of the potential GHG emissions in an abandonment scenario of pastoralist lands is fundamental in assessing the potential efficacy of livestock intensification policies for GHG reduction. The implicit assumption is that there would be no replacement of the niche currently filled by livestock. This runs against recommendations following CoP21 for rewilding as a means to "recarbonize" marginal agricultural land (Lal 2016). Indeed, both wild ruminants and termites would be expected to quickly fill these niches (Itoh 2018), while both happen to be methane-producers as well. Not only does the current approach lack guidance on this subject, but quantifying potential emissions is a difficult task in the case of the two main "suspects": there are no available estimates on the current number of wild ruminants (Havlík et al 2014) and the uncertainty of termite emissions is large. Nevertheless, pre-European contribution of bison, elk and deer to methane in North America is estimated to be 86% of current domestic ruminant emissions, including livestock from zero-grazing and mixed systems. Current-day emissions of wild ruminants are further estimated at 4.3% (Hristov 2012).

This estimate of 86% would likely be further elevated if megafauna present before the arrival of the first humans, and subsequently hunted to extinction before European settlement, were included. Data from Siberia support this idea, where Pleistocene methane emissions from megaherbivores would have been much higher than current ones (Zimov & Zimov 2014). Recent debates on conservation approaches linked with 'land sparing' are exploring the rewilding of landscapes, introducing extant megaherbivores or cloning of extinct species to restore the ecosystem functionality lost through early human hunters (Corlett 2016). However, research suggests methane production is positively correlated with herbivore size (Clauss & Hummel 2005), so the contribution of extinct megaherbivores would have been more substantial than of current wild herbivores (Smith et al 2015, Smith et al 2016). Wild ruminants may also be less efficient in feed conversion and therefore stronger GHG emitters than domestic ones, as the latter have been subjected to heavy selection for efficiency (Herrero et al 2011, Smith et al 2015). Thus, although domesticated ruminants may be responsible for large amounts of current-day emissions, their emissions would be expected to be equal to or less than those of historical wild populations (Fig. 1), and have been relatively constant over time, as opposed to fossil fuel emissions, which have increased dramatically since the Industrial Revolution.

In respect to termites, their habitat comprises 68% of terrestrial land cover, a surface representing 77% of the terrestrial Net Primary Productivity (NPP), and they process the equivalent of 28% of terrestrial NPP (Zimmerman et al 1982). While data are scarce, the most recent estimate attributes up to 18-23 Tg CO_2-eq, or 4% of the total global methane emissions, to termites, with ruminant enteric fermentation accounting for 22% (Spahni et al 2011). In a scenario where domestic ruminants would disappear from tropical savannas, and where expansion of wild ruminants would necessarily be prevented in order to keep methane emissions low, it is easy to imagine an increase in termite density to occupy the resulting empty niche. Accounting for wild herbivores and termites will illustrate a pastoralism abandonment scenario with potentially higher GHG emissions, even without the inclusion of methane and nitrous oxide emissions from fires (Romasanta et al 2017), driven in our abandonment scenario by increased catastrophic wildfires due to increased litter buildup.

In summary, the negative repercussions of loss of pastoralist systems are clear, and the subsequent benefits in terms of reduced GHG are doubtful. At the very least, livestock intensification at the cost of pastoralist systems as a strategy to stem climate change should be halted until there are sufficient data with which to inform a complete assessment. This includes one which accounts for emissions in a landscape abandonment scenario. This would, however, require accounting for great variation among various pastoralist systems. It is urgent to build a quantitative understanding of emissions by wild mammalian herbivores, especially given the recent trends in restoration ecology that call for rewilding landscapes (Svenning et al 2016, Murray 2017) – also as an option to mitigate climate change (Cromsigt et al 2018) – and the effectiveness of reforestation for offsetting emissions in landscapes that are naturally kept open by the action of herbivores and fires (Bond 2005). It is also, however, of paramount importance to improve termite emission data, particularly at the landscape scale level, where they are virtually non-existent. They should be used to refine ongoing attempts to establish baseline scenarios in Africa (Hempson et al 2017), along with latest estimates (Pelster et al 2016, Assouma et al 2017) on specific emission intensities for tropical livestock.

The other scenario, where abandoned pastures are developed into intense agriculture, a pattern currently occurring in several regions around the world, bodes ominously for GHG emissions as well. Ploughing of permanent grassland releases much of the carbon stored in the soil, irrespective of tilling practices (Sørensen et al 2014), which can only be regained through subsequent pasture improvement, and has further negative implications for many ecosystem services. Further, fossil fuel use, the main cause of climate change, through the allocation into the atmosphere of carbon stored underground for millions of years, would be exacerbated by shifting away from pastoralist systems. They are much less fuel-dependent than livestock production systems which depend on fodder production (Fig. 1).

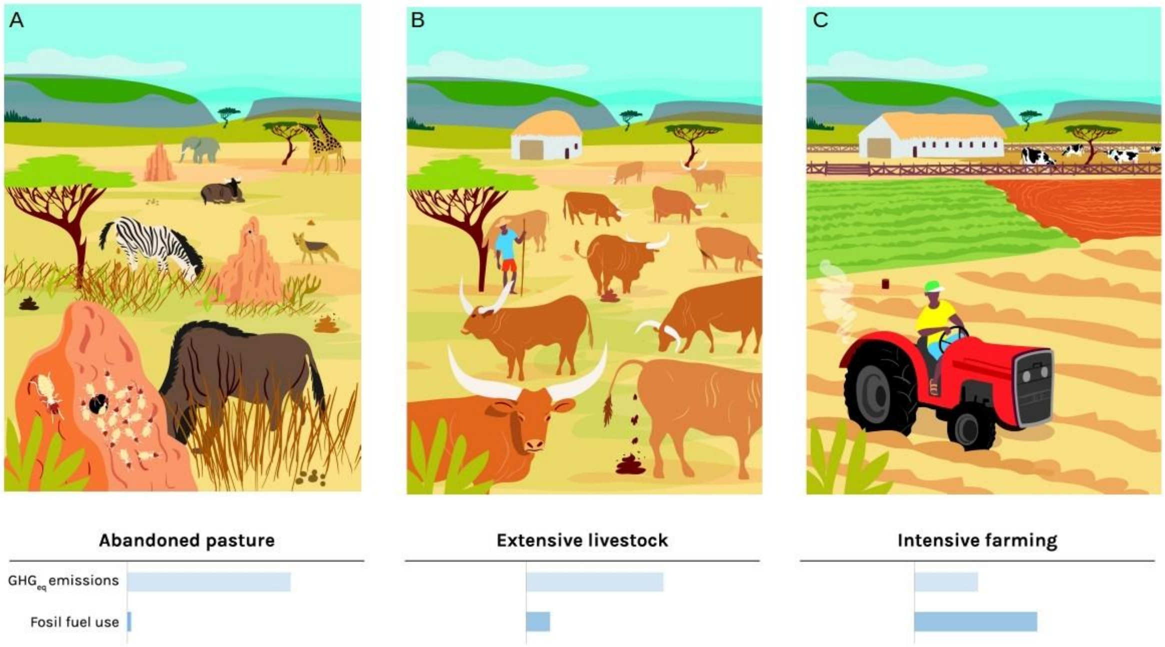

Fig. 1. Conceptual approach for the different GHG emission and fossil fuel scenarios according to type of grazing system. Policies favouring abandonment of pastoralism would convert current pastoralist systems (B) either into abandoned landscapes that keep a similar high level of GHGeq emissions (A) or, in the lands best suited for crop farming, into landscapes cultivated for fodder where GHGeq emissions would decrease but intensity of fossil fuel use, mainly due to increased fodder demand, will multiply (C). The level of GHGeq emissions is determined by conversion models (Gerber et al 2013, but see Pierrehumbert & Eshel 2015). Scales are arbitrary – values for GHGeq emissions and for fossil fuel use are not equivalent.

The challenge of increasing food production while simultaneously reducing GHG is real, and without easy solutions. Agricultural environmental footprint is an area of intense public interest and where government policy can have significant impacts. Unfortunately, flawed scientific underpinnings in other disciplines have already threatened pastoralism, as in the conversion of dry season pastures into cropland to increase production output (de Jode 2010) or privatization of communal lands for higher economic efficiency (Khazanov 2013, Basupi et al 2017). Thus, great caution is to be exercised when eliciting change in this arena. Assessment tools should be used that accurately capture environmental implications of suggested solutions.

Within the existing food production system, policy makers should abstain from promoting the abandonment of pastoralist lands if they are committed to tackling climate change, instead targeting areas of potential improvement within pastoralist systems. This should, of course, be in association with the promotion of sustainable grazing practices, so that the associated benefits of pastoralism are not sacrificed. There is a wide array of available technologies that can contribute to reducing emission intensity within the pastoralist systems (Mushi et al 2015, Gerssen-Gondelach et al 2017) , including the use of manure-fed biogas for access to safe, clean cooking stoves (Arthur & Baidoo 2011, Teenstra et al 2016), adopting improved pasture species (Henderson et al 2017) or adding feed additives that increase food digestibility by livestock (Roehe et al 2016). These options fit better into the concept of "sustainable intensification" than other intensification options criticized in this perspective, and can also positively impact on the income and welfare of pastoralist producers. However, any gains in this direction should be simply considered a "surplus"; the picture should not be distorted with highly sustainable systems blamed for emissions pastoralism is not responsible for. Finally, an adequate evaluation of livestock systems and the derived policy formulation urgently require the adoption of data collection procedures by international organizations such as the Food and Agriculture Organization of the United Nations, national governments and other competent authorities that can clearly separate grass-fed systems from mixed and zero-grazing systems. Better data are needed both in terms of animal numbers under the different systems and of the landscapes they occupy.

References

Arthur R, Baidoo MF (2011) Harnessing methane generated from livestock manure in Ghana, Nigeria, Mali and Burkina Faso. Biomass Bioenergy 35: 4648-4656

Assouma MH, Serça D, Guérin F, Blanfort V, Lecomte P, Touré I, Ickowicz A, Manlay Rj, Bernoux M, Vayssières J (2017) Livestock induces strong spatial heterogeneity of soil CO_2 , N_2O, CH_4 emissions within a semi-arid sylvo-pastoral landscape in West Africa. J Arid Land 9: 210–221

Balmford A, Amano T, Bartlett H, Chadwick D, Collins A, Edwards D, Field R, Garnsworthy P, Green R, Smith P, Waters H, Whitmore A, Broom DM, Chara J, Finch T, Garnett E, Gathorne-Hardy A, Hernandez-Medrano J, Herrero M, Hua F, Latawiec A, Misselbrook T, Phalan B, Simmons BI, Takahashi T, Vause J, zu Ermgassen E, Eisner R (2018) The environmental costs and benefits of high-yield farming. Nat Sustain 1: 477-485

Bassi M (2017) Pastoralists are peoples: key issues in advocacy and the emergence of pastoralists' rights. Nomad People 21: 4–33

Basupi LV, Quinn CH, Dougill AJ (2017) Pastoralism and land tenure transformation in Sub-Saharan Africa: conflicting policies and priorities in Ngamiland, Botswana. Land 6: 89

Bernués A (2017) Animals on the land: ecosystem services and disservices of grazing livestock systems. In: D'Silva J, Webster J (eds) The meat crisis: developing more sustainable and ethical production and consumption. 2nd ed. Earthscan, London, p 67–92

Bond WJ (2005) Large parts of the world are brown or black: A different view on the 'Green World' hypothesis. J Veg Sci 16: 261–266

Campbell BM, Thornton P, Zougmoré R, van Asten P, Lipper L (2014). Sustainable intensification: What is its role in climate smart agriculture? Curr Opin Environ Sustain 8: 39-43

Clauss M, Hummel J (2005) The digestive performance of mammalian herbivores: why big may not be that much better. Mammal Rev 35: 174–187

Corlett RT (2016) Restoration, reintroduction, and rewilding in a changing world. Trends Ecol Evol 31: 453–462

Cromsigt JPGM, te Beest M, Kerley GIH, Landman M, le Roux E, Smith FA (2018) Trophic rewilding as a climate change mitigation strategy? Phil Trans R Soc B 373: 20170440 de Jode H (2010) The obstacles to mobility. In: de Jode H (de) Modern and Mobile. The Future of Livestock Production in Africa's Drylands. IIED & SOS Sahel, London, p 35-47

Eisler MC, Lee MRF, Tarlton JF, Martin GB, Beddington J, Dungait JAJ, Greathead H, Liu J, Mathew S, Miller H, Misselbrook T, Murray P,Vinod VK, van Saun R, Winter M (2014) Agriculture: steps to sustainable livestock. Nature 507: 32–34

Franzei S, Carsan S, Lukuyu B, Sinja J, Wambugu C (2014) Fodder trees for improving livestock productivity and smallholder livelihoods in Africa. Curr Opin Environ Sustain 6: 98–103

Garnett T (2014) Three perspectives on sustainable food security: efficiency, demand restraint, food system transformation. What role for life cycle assessment? J Clean Prod 73: 10-18.

Garnett T (2017) Livestock and climate change. In: D'Silva J, Webster J (eds) The meat crisis: developing more sustainable and ethical production and consumption. Routledge, London, p 31–51

Garnett T, Godde C, Muller A, Röös E, Smith P, de Boer I, zu Ermgassen E, Herrero M, van Middelaar C, Schader C, van Zanten H (2017) 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. FCRN, Oxford

Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Falcucci A, Tempio G (2013) Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. FAO, Rome

Gerssen-Gondelach SJ, Lauwerijssen RBG, Havlík P, Herrero M, Valin H, Faaij APC, Wicke B (2017) Intensification pathways for beef and dairy cattle production systems: Impacts on GHG emissions, land occupation and land use change. Agric Ecosyst Environ 240: 135-147

Havlík P, Valin H, Herrero M, Obersteiner M, Schmid E, Rufino MC, Mosnier A, Thornton PK, Böttcher H, Conant RT, Frank S, Fritz S, Fuss S, Kraxner F, Notenbaert A (2014) Climate change mitigation through livestock system transitions. PNAS 111: 3709–3714

Heffernan O (2017) Sustainability: A meaty issue. Nature 544: S18–S20

Hempson GP, Archibald S, Bond WJ (2017) The consequences of replacing wildlife with livestock in Africa. Sci Rep 7: 17196

Henderson B, Falcucci A, Mottet A, Early L, Werner B, Steinfeld H, et al. Marginal costs of abating greenhouse gases in the global ruminant livestock sector. Mitig Adapt Strateg Glob Change 2017; 22: 199–224.

Herrero M, Gerber P, Vellinga T, Garnett T, McAllister T, Leip A, Opio C, Westhoek HJ, Thornton PK, Olesen J, Hutchings N, Montgomery H, Soussana J-F, Steinfeld H, McAllister TA (2011) Livestock and greenhouse gas emissions: The importance of getting the numbers right. Anim. Feed Sci Tech 166: 779–782

Herrero M, Henderson B, Havlík P, Thornton PK, Conant RT, Smith P, Wirsenius S, Hristov AN, Gerber P, Gill M, Butterbach-Bahl K, Valin H, Garnett T, Stehfest E (2016) Greenhouse gas mitigation potentials in the livestock sector. Nat Clim Change 6: 452–461

Hristov AN (2012) Historic, pre-European settlement, and present-day contribution of wild ruminants to enteric methane emissions in the United States. J Anim Sci 90: 1371-1375

Itoh M (2018) Wildlife in the Exclusion Zone in Chernobyl. In: Itoh M (ed) Animals and the Fukushima Nuclear Disaster. Palgrave Macmillan, Cham, pp 177-187

Khazanov AM (2013) Contemporary pastoralism: old problems, new challenges. In: Sternberg T, Chatty D (eds) Modern Pastoralism and conservation. Old Problems, New Challenges. White Horse Press, Cambridge, p 5-23

Lal R (2016) Beyond COP 21: Potential and challenges of the “4 per Thousand” initiative. J Soil Water Conserv 71: 20A-25A

Manzano Baena P (2012) Shaping policies. Science-policy interface in Natural Resources Management. In: Davies J (ed) Conservation and sustainable development. Linking practice and policy in Eastern Africa. Taylor & Francis, New York and London, IDRC, Ottawa, p 107-126

Manzano P (2015) Pastoralist ownership of rural transformation: the adequate path to change. Development 58: 326–332

Manzano-Baena P, Salguero-Herrera C (2018) Mobile pastoralism in the Mediterranean: arguments and evidence for policy reform and to combat climate change. Mediterranean Consortium for Nature and Culture, Geneva

Merrigan K, Griffin T, Wilde P, Robien K, Goldberg J, Dietz W (2015) Designing a sustainable diet. Science 350: 165-166

Monbiot G (2017) Goodbye – and good riddance – to livestock farming. The Guardian 4 Oct 2017. www.theguardian.com/commentisfree/2017/oct/04/livestock-farming-artificial-meat-industry-animals (accessed 4 June 2018)

Mottet A, de Haan C, Falcucci A, Tempio G, Opio C, Gerber P (2017) Livestock: On our plates or eating at our table? A new analysis of the feed/food debate. Glob Food Sec 14: 1–8

Muller A, Schader C, El-Hage Scialabba N, Brüggemann J, Isensee A, Erb KH, Smith P, Klocke P, Leiber F, Stolze M, Niggli U (2017) Strategies for feeding the world more sustainably with organic agriculture. Nat Commun 8: 1290

Murray M (2017) Wild pathways of inclusive conservation. Biol Cons 214: 206–212

Mushi DE, Eik LO, Bernués A, Ripoll-Bosch R, Sundstøl F, Mo M (2015) Reducing GHG Emissions from Traditional Livestock Systems to Mitigate Changing Climate and Biodiversity. In: Lal R, Singh BR, Mwaseba DL, Kraybill D, Hansen DO, Elk LO (eds) Sustainable intensification to advance food security and enhance climate resilience in Africa. Springer, Heidelberg, p 343-365

Nature Climate Change editorial (2017) Choices to be made. Nat Clim Change 7: 535.

Pelster DE, Gisore B, Goopy J, Korir D, Koske JK, Rufino MC, Butterbach-Bahl K (2016) Methane and nitrous oxide emissions from cattle excreta on an East African grassland. J Environ Qual 45: 1531–1539

Pierrehumbert RT, Eshel G (2015) Climate impact of beef: an analysis considering multiple time scales and production methods without use of global warming potentials. Environ Res Lett 10: 085002

Plieninger T, Hartel T, Martín-López B, Beaufoy G, Bergmeier E, Kirby K, (2015) Wood-pastures of Europe: Geographic coverage, social–ecological values, conservation management, and policy implications. Biol Cons 190: 70–79

Poore J, Nemecek T (2018) Reducing food’s environmental impacts through producers and consumers. Science 360: 987–992

Ripoll-Bosch R, de Boer IJM, Bernués A, Vellinga TV (2013) Accounting for multi-functionality of sheep farming in the carbon footprint of lamb: A comparison of three contrasting Mediterranean systems. Agr Syst 116: 60–68

Ripple WJ, Smith P, Haberl H, Montzka SA, McAlpine C, Boucher DH (2014) Ruminants, climate change and climate policy. Nat Clim Change 4: 2–5

Roehe R, Dewhurst RJ, Duthie CA, Rooke JA, McKain N, Ross DW, et al. Bovine host genetic variation influences rumen microbial methane production with best selection criterion for low methane emitting and efficiently feed converting hosts based on metagenomic gene abundance. PLoS Genet. 2016; 9: e93331

Romasanta RR, Sander BO, Gaihre YK, Alberto MC, Gummert M, Quilty J, Nguyen VH, Castalone AG, Balingbing C, Sandro J, Correa Jr T, Wassmann R(2017) How does burning of rice straw affect CH_4 and N_2O emissions? A comparative experiment of different on-field straw management practices. Agr Ecosyst Environ 239: 143–153

Sayre NF, Davis DK, Bestelmeyer B, Williamson JC (2017) Rangelands: where anthromes meet their limits. Land 6: 31

Schader C, Muller A, El-Hage Scialabba N, Hecht J, Isensee A, Erb KH, Smith P, Makkar HPS, Klocke P, Leiber F, Schwegler P, Stolze M, Niggli U (2015) Impacts of feeding less food-competing feedstuffs to livestock on global food system sustainability. J R Soc Interface 12: 20150891

Smith FA, Lyons SK, Wagner PJ, Elliott SM (2015) The importance of considering animal body mass in IPCC greenhouse inventories and the underappreciated role of wild herbivores. Glob Change Biol 21: 3880–3888

Smith FA, Hammond JI, Balk MA, Elliott SM, Lyons SK, Pardi MI, Tomé CP, Wagner PJ, Westover ML (2016). Exploring the influence of ancient and historic megaherbivore extirpations on the global methane budget. PNAS 113: 874-879

Sørensen CG, Halberg N, Oudshoorn FW, Petersen FW, Dalgaard R (2014) Energy inputs and GHG emissions of tillage systems. Biosyst Eng 120: 2-14

Spahni R, Wania R, Neef L, van Weele M, Pison I, Bousquet P, Frankenberg C, Foster PN, Joos F, Prentice IC, van Velthoven P (2011) Constraining global methane emissions and uptake by ecosystems. Biogeosciences 8: 1643–1665

Svenning J-C, Pedersen PBM, Donlan CJ, Ejrnæs R, Faurby S, Galetti M, Hansen DM, Sandel B, Sandom CJ, Terborgh JW, Vera FWM (2016) Science for a wilder Anthropocene: Synthesis and future directions for trophic rewilding research. PNAS 113: 898–906

Teenstra E, Andeweg K, Vellinga T. Manure helps feed the world. Integrated Manure Management demonstrates manure is a valuable resource. Wageningen: GACSA & Wageningen UR; 2016.

The Economist. (2014) Meat and greens. The Economist 18 Jan 2014. www.economist.com/node/21594348 (accessed 4 June 2018)

Veblen KE, Porensky LM, Riginos C, Young TP (2016) Are cattle surrogate wildlife? Savanna plant community composition explained by total herbivory more than herbivore type. Ecol Appl 26: 1610-1623

Wellesley L (2015) Can eating less meat help reduce climate change? BBC News 24 Nov 2015. www.bbc.com/news/science-environment-34899066 (accessed 4 June 2018)

White RR, Hall MB (2017) Nutritional and greenhouse gas impacts of removing animals from US agriculture. PNAS 114: E10301–E10308

Wible B, Mervis J, Wigginton NS (2014) Rethinking the global supply chain. Science 344: 1100-1103

Wirsenius S, Hedenus F (2017) Policy strategies for a sustainable food system: options for protecting the climate. In: D'Silva J, Webster J (eds) The meat crisis: developing more sustainable and ethical production and consumption. Routledge, London, p 301–316

Wolf J, Asrar GR, West TO (2017) Revised methane emissions factors and spatially distributed annual carbon fluxes for global livestock. Carbon Balance Manag 12: 16

Zimmerman PR, Greenberg JP, Wandiga SO, Crutzen PJ (1982) Termites: a potentially large source of atmospheric methane, carbon dioxide, and molecular hydrogen. Science 218: 563-565

Zimov S, Zimov N (2014) Role of megafauna and frozen soil in the atmospheric CH_4 dynamics. PLoS One 9: e93331