Journal of Environmental Science and Engineering B 2 (2014) 586-601
Formerly part of Journal of Environmental Science and Engineering, ISSN 1934-8932

Severe Methodological Deficiencies Associated with Claims of Domestic Livestock Driving Climate Change

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Received: March 04, 2013 / Accepted: March 17, 2014 / Published: April 20, 2014.

Abstract: Reduction of global livestock numbers and meat consumption have been recommended for climate change mitigation. However, the basic assumptions made to come up with that kind of recommendations reveal severe methodological deficiencies: (1) Carbon footprint, emission intensity, and life-cycle assessments of domestic livestock products reported in scientific literature consistently overlooked the necessity of correcting non CO_2 GHG (greenhouse gas) emissions (nitrous oxide and methane) from managed ecosystems for baseline emission scenarios over time and space (pristine ecosystem and/or pre-climate change emissions); (2) Uncertainties associated with the climate sensitivity of anthropogenic GHG-emissions have been ignored; (3) Inconsistencies in the methodological treatment of land use change (deforestation) in emission intensity calculations (per unit of product) can be detected in the literature; (4) The virtual lack of a discernable livestock signal in global methane distribution and historical methane emission rates has not been acknowledged; theoretical bottom up calculations do not reflect the relative insignificance of livestock-born methane for the global methane budget; (5) Potential substrate induced enhancement of methane breakdown rates have not been taken into consideration. A tremendous over-assessment of potential livestock contribution to climate change is the logical consequence of these important methodological deficiencies which have been inexorably propagated through recent scientific literature.

Key words: Global warming, GHG (greenhouse gases), methane, nitrous oxide, biodiversity, deforestation, baseline scenarios, life cycle assessment, carbon footprint, emission intensity.

1. Introduction

The famous FAO (Food and Agriculture Organization of the United Nations) report "Livestock's Long Shadow" [1] held domestic livestock in general and grassland based production systems in the (sub)tropics in particular, responsible for serious environmental hazards such as climate change, claiming that 18% of anthropogenic GHG (greenhouse gas) emissions are being caused by livestock; more than by the transportation sector. This message produced a storm of incrimination of animal husbandry by the major media around the world. The concern about livestock's alleged contribution to climate change culminated with a hearing in the European Parliament in 2009 on the topic "Less Meat = Less Heat". Few reviews challenged this claim, and those that did received little attention from the media. Pitseky et al. [2] revealed the double standard applied by the FAO in this matter: Whereas a full life-cycle assessment for GHG emissions from livestock products was applied (considering all potential emission sources from land clearing to meat and milk consumption), only fuel consumption was taken into account for the transportation sector.

Nevertheless, even in serious scientific journals authors keep claiming that food consumption patterns potentially contribute to climate change [3-5], an issue still deliberately picked up by prominent media, such as The Economist [6]. Environmentalists recommend a drastic reduction of ruminant livestock at a global scale in order to mitigate climate change and to "yield

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important social and environmental co-benefits" [7]. In another recently published report "Tackling Climate Change through Livestock" [8], the FAO also restates livestock's influential role for climate change, but reduces somewhat the contribution of global domestic livestock to anthropogenic GHG emissions to "only" 14.5%. However, it still:

- contains the same methodological deficits;
- ignores the uncertainties associated with the climate sensitivity of so-called GHGs;
- ignores the inconsistencies between some of its conclusions and several empiric observations in the real world.

2. Methodological Approach

This is a critical review of scientific literature holding livestock responsible for appreciably contributing to climate change. The methodologies applied to come up with such accusations are rigorously assessed in light of:

- lesser known publications not commonly referred to by the mainstream scientific community;
- empirical facts and data determined on a global scale; as well as,
- logical reasoning and rigorous cross checking.

3. Results and Discussion

3.1 How Reliable is the Basic Science on Anthropogenic Climate Change?

The basic assumption which has to be accepted when blaming livestock for causing climate change is noticeable climate sensitivity to anthropogenic greenhouse gas emissions. The overwhelming majority of scientists and scientific organizations (including the FAO) do not question this assumption, given the conclusions of the latest IPCC (Intergovernmental Panel on Climate Change) reports [9, 10] supposedly "unanimously" agreed upon by "hundreds of scientists". However, just focusing on a few critical points, it becomes evident that there is still room for considerable doubt about the above-mentioned assumption of noticeable climate sensitivity to human related greenhouse gas emissions:

(1) Mean global temperatures were flat in the past 15 years, and even slightly decreased over the past 10 years, in spite of steadily increasing CO_2-levels in the atmosphere (Fig. 1) which even caused a remarkable greening of deserts in the past 30 years by fertilizing plants and making them more drought tolerant [11]. This is an empirical observation contradicting all the scenarios of projected temperatures published in the AR4 (fourth IPCC assessment report) and earlier ones. These scenarios are summarized in Fig. 2;

(2) There is an overwhelming number of peer reviewed papers, and among them several published recently such as Refs. [12-19] that acknowledge the existence of various eras after the end of the latest ice age (about 12,000 years ago), which were warmer than or at least as warm as the present age (in spite of the pre-industrial atmospheric CO_2-levels at those times);

(3) Yet, in its TAR (Third Assessment Report), the IPCC [20] prominently featured an iconic graph, first published by Mann et al. [21], in which the temperatures of pre-industrial warm and cold periods, the Medieval Warm Period and the Little Ice Age, had been virtually leveled out, just to show a dramatic temperature increase in the twentieth century. This so called "Hockey Stick" has been exposed to represent scientific bias [22], a serious critique that never has been credibly refuted;

(4) In the AR4-IPCC report, 16 variables are identified as forcing agents of global warming/climate change and are used in the models (however, a number of natural forcing agents are missing). The level of understanding for 11 of them was specified by the IPCC as "very low to low" as shown in Table 2.11 of Ref. [9]. Yet the IPCC comes up with a 90% to 95% certainty in the results of its models, a conclusion which is scientifically incomprehensible, as models based on uncertain variables require empirical validation. As far as the modeled temperature projections for a variety of emission scenarios published by AR4-IPCC

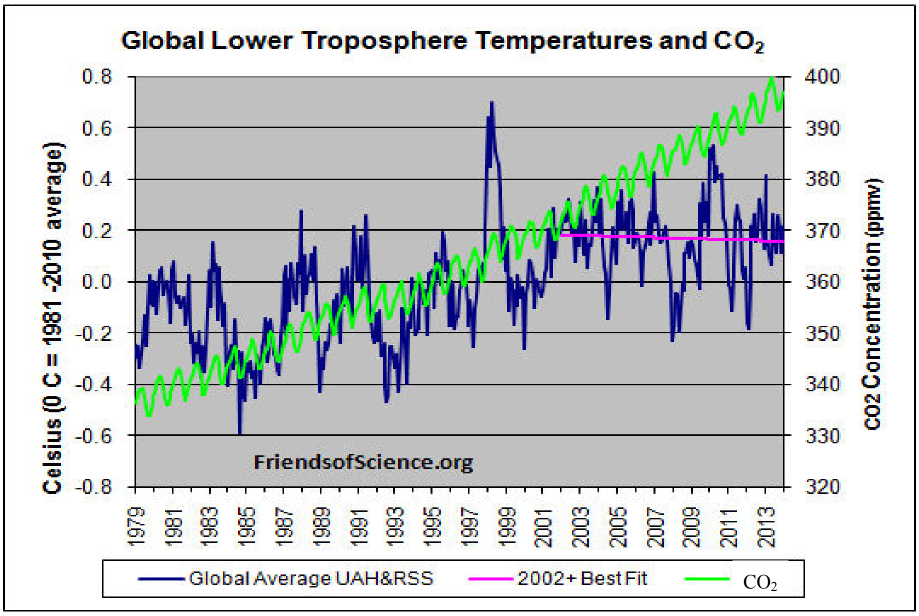

Fig. 1 Observed real world lower troposphere temperature anomalies (average of two analyses of MSU (Microwave Sounding Unit) data from NOAA (National Oceanic and Atmospheric Administration) satellites as processed by UAH (University of Alabama Huntsville) and RSS (Remote Sensing Systems), based on thousands of daily measurements, uniformly distributed over the globe). The best fit line from January 2002 to January 2014 indicates a decline of 0.02 °C per decade. The sharp temperature spikes in 1998 and 2010 are El Niño events. The green line shows the CO_2 concentration in the atmosphere, as measured at Mauna Loa, Hawaii [33].

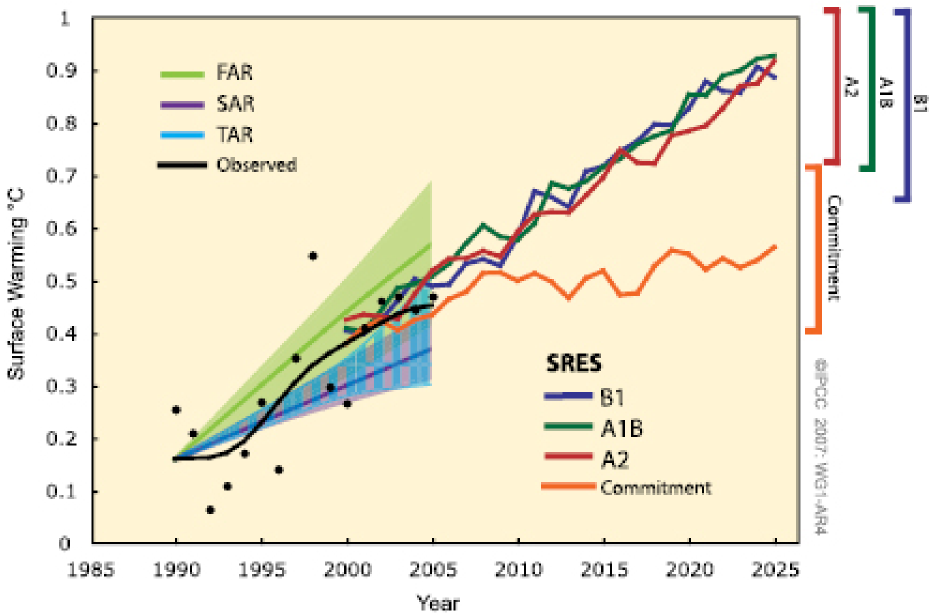

Fig. 2 Multi-model mean projections of global warming for various emission scenarios with uncertainty ranges indicated against the right hand axis, the orange curve (commitment) showing the projection of warming if greenhouse gas and aerosol concentrations were held constant from the year 2000. Projections from earlier IPCC reports, FAR, SAR, TAR (the first, second and third assessment reports), and observed temperatures from 1990 to 2005 are also indicated [9].

(and earlier reports) can already be tested with observed temperature data, recent temperatures are located well outside the confidence intervals of all IPCC-models, which, therefore, did not pass their validation exam as demonstrated in Fig. 1.4 of the leaked second order draft of IPCC-AR5 [23, 24].

However, the IPCC has chosen not to show this graph in the final version of AR5 (the 5th Assessment Report). Additionally, in the Summary for Policy Makers [10] the "observed reduction in surface warming trend over the period 1998-2012" is mentioned on page 15, hidden in the text body and provided with a number of potential explanations. TRCS (The Right Climate Stuff) research team, a volunteer group composed of more than 25 persons, retired NASA (National Aeronautics and Space Administration) Apollo Program veterans (scientists and engineers), also concluded that the IPCC climate models "are seriously flawed because they do not agree very closely with measured empirical data" [25];

(5) The disagreement between models and observed temperature data suggests that the IPCC has largely overestimated within its models the assumed positive feedbacks of the miniscule warming potential of additional CO_2 in the atmosphere [26-28], while in nature negative feedbacks are likely to be in effect [29-31]. The tiny warming of anthropogenic CO_2 in the absence of feedbacks has recently been confirmed by Gervais [32].

3.2 Livestock's Role in GHG (Greenhouse Gas) Emissions

Even if we ignored the above-mentioned objections and kept assuming measurable climate sensitivity to anthropogenic greenhouse gas emissions, there still remain many inconsistencies between empirical facts (and logical reasoning) and the claims of those authors who blame livestock for causing climate change ("Meat = heat"):

3.2.1 CO_2 Emissions and Carbon Cycling

CO_2 emitted by livestock respiration and forage digestion, including the emissions resulting from the consumption of meat and milk, does not increase atmospheric CO_2 levels as it is part of the natural carbon cycle. Not a single livestock-born CO_2 molecule is added additionally to the atmosphere as it has been captured previously from the atmosphere through photosynthesis. The amount of CO_2 released annually by livestock is offset by the photosynthesis of re-growing forages. In fact, long lasting animal products, such as leather and bones, can store carbon for a long period, before it is eventually released again to the air. FAO [1, 8] recognizes the CO_2 neutrality of livestock-born emissions; some other authors (mostly from the popular science and environmentalist arenas) do not with inadmissable arguments [34]: Correct! Domestic livestock is a product of Homo sapiens' survival skills and cultural creative power, but so is CO_2 fixing forage production, pasture cultivation and grassland management. And still, livestock does not exhale a single CO_2 molecule, which had not been captured in the herbage biomass before and which will not be offset by carbon sequestration in re-growing herbage.

The wider natural carbon cycle over geological periods of time, which includes carbonate deposits in the oceans, CO_2 fixation in the lithosphere and fossil fuels, as well as CO_2 recycling to the atmosphere through volcanism and rock-weathering, is not discussed here, although it has been crucial for the steady decline of the CO_2 concentrations in the atmosphere during earth's history, associated with the evolution of highly efficient mechanisms within plants to extract this trace compound, so essential for life, from the air for photosynthesis [35].

The only present-time sources of additional CO_2 emissions caused by livestock husbandry beyond the natural carbon cycle are:

- fossil fuel consumption during the production process;
- deforestation for pasture establishment;
- soil organic matter decomposition from degrading grassland.

These additional carbon sources need to be commented as follows.

3.2.1.1 Fossil Fuel Consumption

Obviously, fossil fuel consumption is considerable when livestock is predominantly grain-fed and held in confinement (e.g. feedlots). As the annual cultivation of soil is the dominant source of greenhouse gas emissions in primary production [36] and as feed conversion efficiency is lower for ruminants than for monogastric animals, such as pork and chicken [37, 38], grain-fed beef production is a source of considerable CO_2 emissions from the combustion of fossil fuels. In grazing systems, however, the use of fossil fuels is comparatively low or almost negligible, as investments in soil tillage, fertilization, forage harvest and transportation are often marginal or even zero, particularly in (sub)tropical regions. Typically, estimates of greenhouse gas emissions by beef cattle are based on concentrate dominated diets. This provides a considerable distortion of reality when the proportion of grazed herbage increases in the diets, which normally implies a considerable decline in fossil fuel consumption and therefore CO_2-emissions.

3.2.1.2 Deforestation

As far as deforestation for pasture establishment is concerned, what is often overlooked is that this produces one single emission (of 151 t of CO_2 per ha in the average in the case of (sub)tropical South America for example, according to Ref. [39]) at the moment of deforestation or/and shortly after. There is no consistent manner in the literature of methodologically treating CO_2 emissions from deforestation [40] for "life-cycle assessments" (analysis of total environmental impact per unit of a product) or for the appraisal of "emission intensities" (total emissions of GHGs per unit of a product).

The only continent the latest FAO report [8] is blaming for CO_2 emissions from deforestation for pasture establishment is Latin America and Caribbean. South America is charged with the very high "emission intensity" of 100 kg CO_2 equivalent per kg of CW (carcass weight) produced, of which 40 kg CO_2 eq. per kg CW is attributed to deforestation. This is justified with the ascertainment that in other continents there have been no significant deforestations for pastureland expansion recently. However, in other continents, particularly Europe, extensive deforestation took place already centuries ago to establish permanent grasslands.

Mathematically the term "emission intensity" describes the emission of a certain quantity of CO_2 equivalent necessary for producing one kg of a product (in this case carcass) under certain conditions. It is questionable to charge this mathematical term with emissions which are not related to the generation of this particular product. For example, while deforesting a specific area of land, beef production is being carried out on other pasturelands, already established earlier. It is methodologically illegitimate to allot the one-time CO_2 emission from deforestation to any accidentally chosen quantity of a product (e.g. yearly beef production in South America) as is done by the FAO [8].

The single emission from deforestation is generated (and tolerated) in order to produce beef on the new pastureland to be established for a very long period of time in the future (hundreds of years just like on European grasslands). However, when the single "carbon debt" from deforestation is spread over the accumulated production from the deforested area over centuries, the specific emission per kg of product (or "emission intensity") from deforestation tends towards zero.

Therefore other continents such as Europe are treated correctly in the FAO report, by disregarding emissions from "LUC (Land Use Change)". According to the FAO methodological approach, 500 years ago, when there was still ongoing deforestation in Europe (which still has 33% of forested area today, excluding Russia), Europe once reached similar "emission intensities" as South America today (with forests > 47% of its area [41]). And in 10 to 20 years, when deforestation has come to a halt due to legal, environmental policy or physical limitations, emission intensities in South America will be similar to the ones in Europe today. But the FAO report [8] does not tell readers this. Without an explicit footnote explaining this context, the FAO approach is scientifically dubious. In the tables and figures of the report, values are compared which are not comparable, because they need to be interpreted distinctly and some have (restricted) validity just for the moment. In that way FAO loads (purposely) unrealistically high emission values onto the South American beef industry and onto cattle grazing systems in general. Is this because tropical deforestation reduces competitiveness in the agricultural sector of industrialized countries [42]?

Furthermore it is considered noble and highly ethical to castigate deforestation, particularly in the Amazon, in order to mitigate climate change and loss of biodiversity. However, in the semiarid Chaco of Paraguay, we can show that deforestation for pasture establishment diversifies the habitats and therefore promotes species richness (as demonstrated in gráfico 1 of Ref. [43]), provided the legal land use restrictions of preserving almost 50% of the surface area of each farm in pristine condition (in the form of a nature reserve, bush corridors and islands) are respected, as they are by >90% of the land owners. The additionally created habitats and resources are extensively used by wildlife too. These refer to the bush border effects over many kilometers, savannah-like landscapes, nutritious pastures and rain water collection reservoirs [43, 44].

Part of the "carbon debt" produced at the moment of deforestation is amortized by the considerable amounts of carbon captured and stored in the soil under pastures. This refers to deep rooting tropical grasses [45] and legumes, such as the planted forage shrub *Leucaena leucocephala* [46], and even to spontaneous bush encroachment, which is undesirable in pastures and needs therefore constant control, but stores quite some carbon in the ligneous organic matter kept in steady state equilibrium between vigorous regrowth and decomposition. Furthermore, occasional fires in grass and woodlands also can contribute to Carbon storage as a fraction of the wood, which is burned, is converted into charcoal representing a stable carbon pool in the soil [47, 48].

3.2.1.3 Soil Degradation and Overgrazing

Pasture degradation due to overgrazing is not an inherent characteristic of grazing systems. It is, however, more frequently observed on communal grazing lands in (semi) arid regions than on privately owned lands [1, 49]. Under the constellation of public land and private livestock ownership, there is little interest in private investments in land rehabilitation. Whereas the conversion of native forest into pasture may increase carbon stocks in soil under certain conditions [50], poor management of pastures leads to a reduction of soil carbon [51]. Well managed grasslands are stable ecosystems with no net CO_2 emissions and considerable C storage capacity [52, 53]. In the United States of America, the observed slow decline in the grazing land base in the past decades was generally offset by slight increases in rangeland health and advances in grazing technology [54]. Also in other countries, like Argentina, Australia, and South Africa, there were, anecdotally, positive rangeland health trends during the past century as improved range management practices became more widely used.

3.2.2 Methane Emissions and Cycling

Methane is an atmospheric constituent of only 0.00018% (vol.) which is less than 2 molecules in a million. Just like CO_2, methane emissions also form part of a natural cycle. Oxidation by OH radicals in the atmosphere (modulated by solar ultraviolet radiation, air humidity, and tropospheric ozone) and decomposition by aerobic methanotrophic bacteria in the soil are the major identified methane sinks [55], bringing about a relatively short atmospheric methane lifetime of 8.7 ± 1.3 years according to the IPCC [9]. Recently, Sundqvist et al. [56] showed a net uptake of methane by green plants (both, in the field and in the lab). They suggest that the omnipresence of bacteria with the ability to consume methane could be a possible explanation for their observations. These results show that plant canopies are playing an important (and hitherto unknown) role as a sink in the global methane cycle.

Methane consumption by methanotrophic bacteria can be considered an autocatalytic process [57], where an enhanced substrate (methane) concentration stimulates the "catalyst's" (bacteria) multiplication. Also, in the case of chemical methane breakdown in the atmosphere to the final products H_2O and CO_2, the reaction velocity (as a general rule of chemical reactions) strongly depends on the concentration of the reaction participants, methane and OH radicals (particularly because their atmospheric concentrations are at a very low order of magnitude). Quirk [58] showed that El Niño induced higher air humidity, associated with an enhanced density of OH radicals consistently increased the sink for methane (i.e. accelerated methane breakdown rate). A similar effect is to be expected with an increased atmospheric methane concentration (while more difficult to demonstrate). Therefore, any change of emission rate also modulates the rate of methane degradation producing a new atmospheric methane concentration as a consequence of a new steady state equilibrium between sources and sinks. On the other hand, a constant emission rate does not change methane concentration in the atmosphere as it is counteracted by a constant or oscillating rate of break down.

Consequently, a constant global livestock number does not increase atmospheric methane, in spite of continuous emissions from ruminant enteric fermentation and manure management. Only an increasing global livestock number could eventually bring about a new steady state equilibrium at a slightly higher atmospheric methane concentration. Therefore, pre-climate change baselines of methane emissions from livestock and global livestock numbers have to be taken into account when assessing the potential impact of domestic animals on climate change. There is, however, quite a bit of dissent on the question of when modern, GHG-induced climate change began (1850 or 1970 or 1990 or not at all?) and with what respective figures. Even the methane emissions by the additional livestock reared after the date assumed to be the beginning of climate change cannot simply be added up over time. Those emissions need to be corrected by the expected enhanced methane decomposition rate, just taking into account the difference of the steady state atmospheric methane concentration built up since that cut-off date due to emissions from the additional domestic livestock.

To determine net anthropogenic emissions from an agro-ecosystem, it is also necessary to correct the measured methane emissions for the baseline emissions which would occur anyway in the natural ecosystem, which meanwhile has been replaced by a managed ecosystem at the very same location. This principle also applies for other non CO_2 GHGs, such as nitrous oxide (Section 3.2.3). Areas formerly populated by large herds of wildlife or areas comprising wetlands, drained later on, could emit even less methane after a land use change towards pastoral land for livestock grazing than did the pristine ecosystem. Moreover, further correction is needed for in situ degradation of methane emitted by livestock, as certain pastoral ecosystems may represent a net sink and not a net source for methane [59], another empirical observation which reduces the utility of bottom-up calculations of methane emissions without considering the eco-systemic context of methane cycling.

Neither FAO [1, 8], nor WWF (World Wide Fund for Nature) [38], nor Vries and Boer [37] in their review of scientific life-cycle assessments for animal products, nor the IPCC [60] in its "Guidelines for National Greenhouse Gas Inventories" consider baseline scenarios over time and space for methane or nitrous oxide. Nor do these publications carry out any corrections for in situ methane degradation, taking into account the sinks counteracting livestock-born methane emissions. They consistently interpret all the direct and indirect emissions of methane (and nitrous oxide) from livestock or from managed agro-ecosystems at a 100% level as an additional anthropogenic source of GHG-emission (along with fossil fuel-born CO_2). Baseline emissions are treated as if nonexistent. A tremendous overestimation of anthropogenic emissions is the obvious consequence of these simplified bottom-up calculations found in the literature, supposedly scientific. Herrero et al. [5] also repeat these fundamental errors in their otherwise comprehensive review on "biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems".

3.2.2.1 Historic Methane Emissions and Livestock

As shown in Fig. 3, the growth rate of atmospheric methane began slowing down in the early 1980s. The mean methane concentration even topped out for a few years around the change of the millennium, just when cattle husbandry was expanding at a considerable rate, particularly in South America. Between 1990 and 2007, when mean atmospheric methane concentration stabilized completely, the global cattle and buffalo population rose by more than 125 million head, or 9% [61]. This empirical observation is hardly consistent with a domestic livestock contribution to the anthropogenic methane emissions of 35% to 40% as claimed by Steinfeld et al. [1] on the basis of theoretical bottom up estimates. On the other hand, the IAEA (International Atomic Energy Agency) [62] acknowledges domestic livestock being a minor player within the global methane budget because of the poor concordance between global livestock numbers and mean atmospheric methane concentration.

Historical increases of methane concentrations in the atmosphere are best explained by rising fossil fuel extraction and use, as well as the associated technological quality standards, taking into account the considerable gas leakages from older pipeline systems [63]. Also, the stabilization of methane emissions in the 1990s is very likely to be linked to technological changes in fossil fuel production and use. This was suggested by Aydin et al. [64] on the basis of the analysis of ethane as an indicator of fossil fuel-born emissions, detected in air enclosures in firn ice from Greenland and Antarctica. The replacement of leaking pipelines by high quality modern ones from 1970 on in western countries and during the 1990s in the former Soviet Union (particularly in Siberia) best explains the drastic decline of methane growth rate (to even below zero, Fig. 4) towards the end of the last century.

Since about 2008, atmospheric methane has been rising again, but only at about half that of the pre-1990 rate. Quirk [58] suggests that this recent increase of methane emission rate is largely due to natural atmospheric changes modulated by El Niño, La Niña

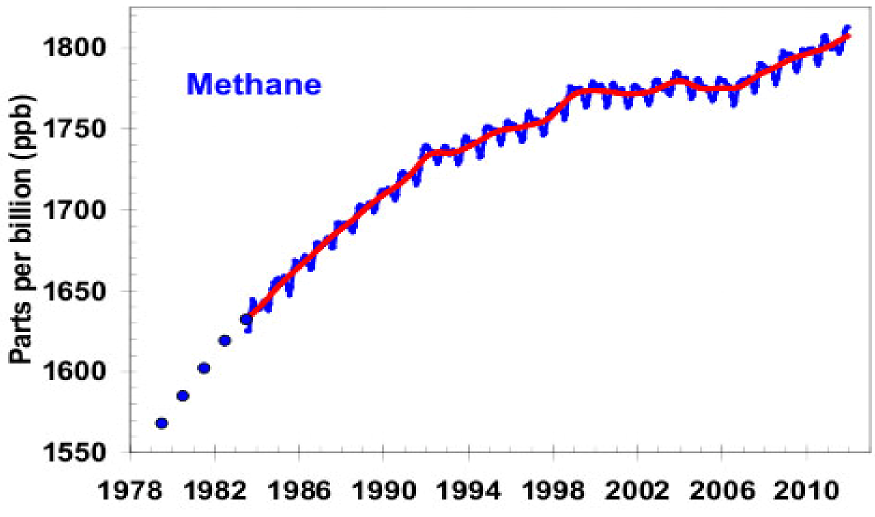

Fig. 3 Mean global atmospheric methane concentration [65].

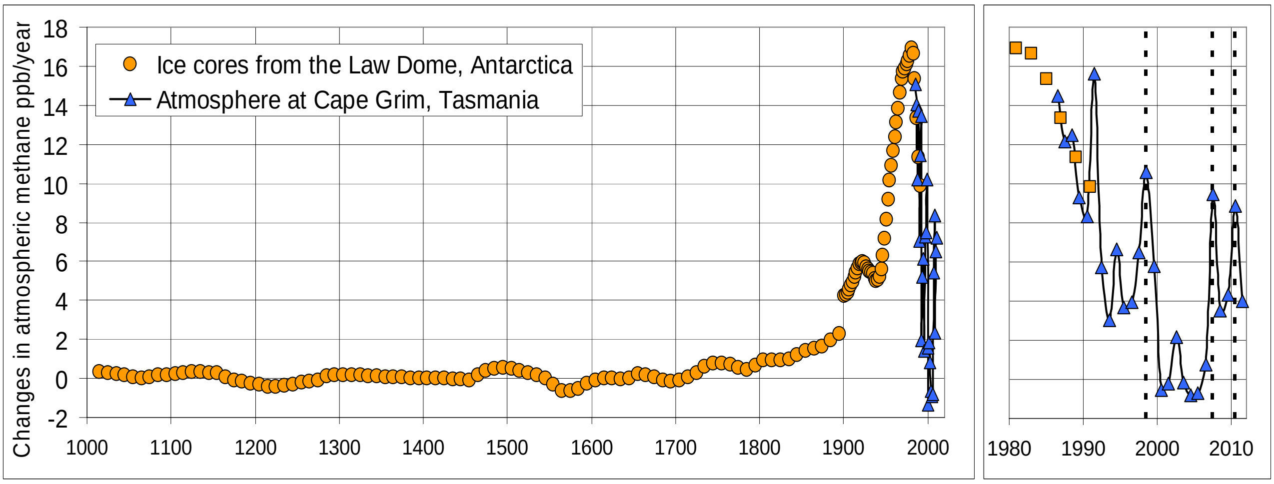

Fig. 4 Annual changes in atmospheric methane in parts per billion derived from ice core up to 1990 and direct atmospheric measurements at Cape Grim (Tasmania) from 1983 to 2011 AD. The peaks in the direct atmospheric measurements reflect the influence of El Niños. The peak in 1991 is an indirect effect from the eruption of Mt. Pinatubo in June 1991 and the 1998, 2006 and 2010 El Nino's are marked by dashed lines [66].

and volcanoes. El Niños enhance absolute air humidity and therefore OH radical density, and volcanoes emit high quantities of SO_2 which competes with CH_4 for OH radicals, thus slowing down methane breakdown. No livestock signal is discernible in the annual variability of atmospheric methane.

3.2.2.2 Geographical Distribution of Livestock and Methane

Contrary to the frequently repeated claims of ruminant enteric fermentation and manure disposal contributing considerably to global methane emissions [1, 5, 39, 67, 68], based on theoretical bottom up calculations, global data show no discernible relationship between atmospheric methane concentrations, as measured by the European satellite ENVISAT over three years, and livestock distribution (Fig. 5): There are regions which are highly populated by livestock with very low (NE-Argentina, Uruguay, Victoria-Australia) and very high (southern China) mean atmospheric methane concentrations, and there are regions with hardly any livestock and very high (parts of Siberia and Amazonia) or relatively low (Sahara) methane concentrations, respectively. Highly populated India, which represents the subcontinent with the highest cattle and buffalo density worldwide, is characterized by moderate methane concentrations. According to the global methane distribution, particularly strong emitters seem to be wetlands in Siberia, humid tropical forests, and paddy rice fields in China. Bottom up estimates of methane emissions from livestock are strikingly different from the atmospheric methane concentrations found in the real world. This allows only one conclusion: Livestock is not an important factor in the global methane budget. Its role has been considerably overestimated by most authors and organizations, such as FAO, IPCC and WWF.

The role of livestock-born methane in the global methane budget is completely dwarfed once the substantial amounts of methane that occur (as clathrates) in and below the permafrost layer in the Arctic are taken into account. It is often under pressure, having been capped by the ice layer and enters the atmosphere through cracks and mud volcanoes (pingos). Muskeg and its cousin peat also produce methane. Large amounts of methane also occur on recent sediments of continental slopes and clathrates have been found on ocean bottoms under low temperature and high pressure conditions. Such sediments are sometimes disturbed by earth movements or slumping, producing sudden gas emissions at the ocean surfaces which have been pointed to as culprits for capsized ships.

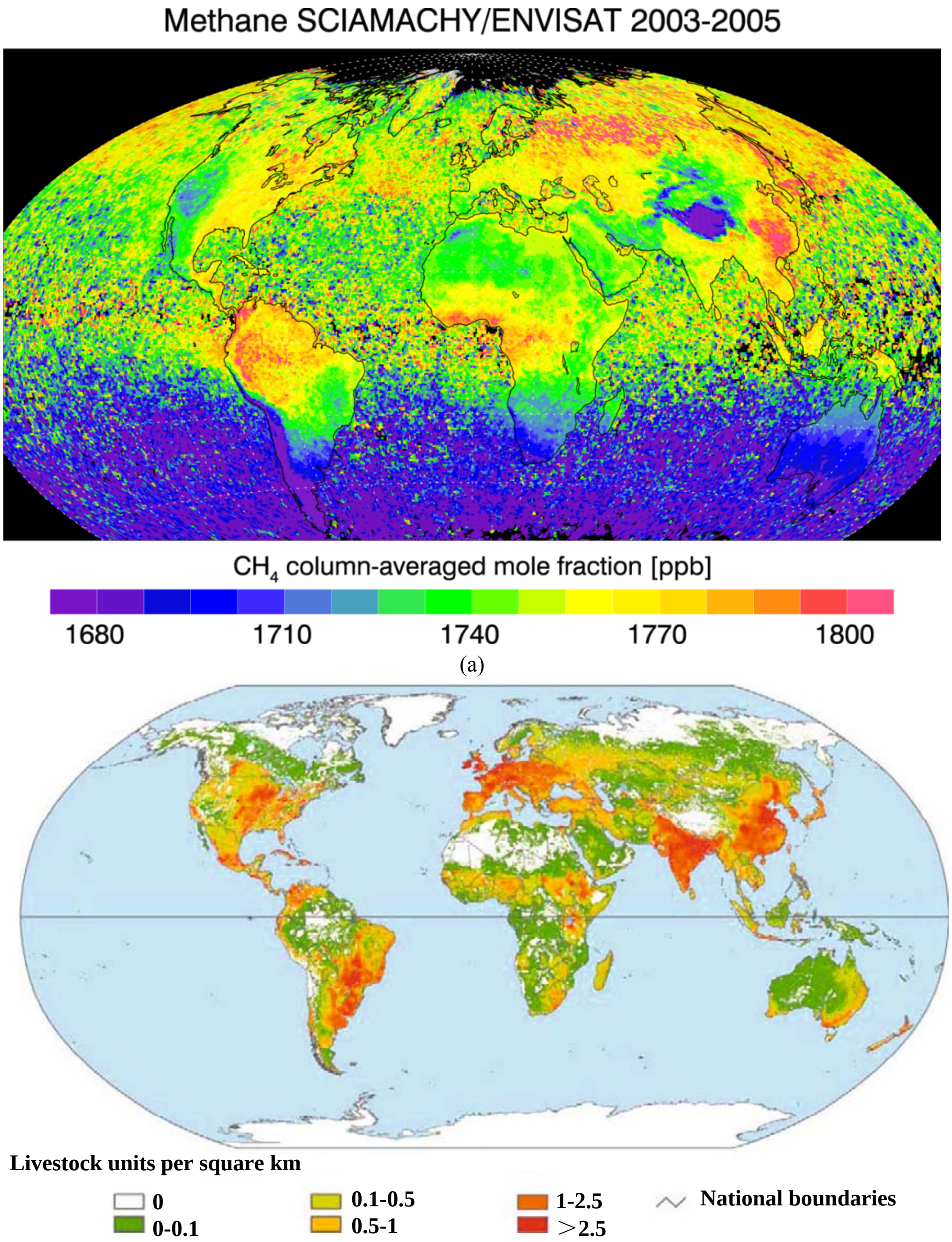

Fig. 5 (a) Global atmospheric methane distribution as measured by the ENVISAT satellite over three complete years, 2003-2005 [69, 70]; (b) Global total livestock distribution of both ruminants and monogastrics [1]. There is no discernible geographical relationship between methane and livestock distribution.

3.2.2.3 Energy Loss through Methane Emissions by Livestock

The FAO 2013 report [8] reckons that methane emissions by ruminants damages production as they constitute a waste of nutritional energy. Of course, methane emissions deliver energy to the environment, but do not spoil it, as methane is a (so far) unavoidable by-product of anaerobic degradation (by rumen cellulolytic bacteria) of the most widespread substance in the biosphere, cellulose. Without methanogenesis, hydrogen (H_2) would accumulate in the rumen and inhibit ongoing fermentation and digestion by negative feedback [71]. Thanks to the methane emissions, ruminants can make use of the high fiber diet growing abundantly on the enormous terrestrial areas marginal to crop agriculture, and convert it into precious food for humans (meat and milk), as well as skins, fibers and other useful products. As long as there are no effective and inexpensive technologies available to manipulate rumen metabolism in order to cut back methane emissions without hampering the digestibility of fiber-rich diets, methane emissions seem to be unavoidable for the very important contribution of ruminants to food security and livelihood resources for humanity [72]. To achieve this, various enteric methane abatement strategies are being followed up in ongoing research activities, such as strengthening methanotrophic bacteria in the rumen or reducing methanogens by specific phages (bacterial viruses) while trying simultaneously to establish reductive acetogens to outcompete the methanogens for excess hydrogen in the rumen [73].

In spite of the relatively low feed-use efficiency (kg of dry matter consumed per kg of product) of ruminants grazing on the vast areas covered by grasslands at a global scale, they make use, as efficiently as possible, of the huge amounts of the otherwise useless fiber growing there in abundance. In the absence of alternative uses of huge areas it does not make sense to blame grassland based systems for low feed-use efficiency and high emission intensities, as is frequently done in modern scientific literature [5, 7, 8].

3.2.3 Nitrous Oxide Emissions and Cycling

N_2O (Nitrous oxide) is a natural atmospheric trace constituent of less than 0.000035% (vol.). It is the product of a lateral circuit of the nitrogen cycle. Whenever aerobic nitrification (bacteria mediated oxidation of ammonia to nitrate) and particularly anaerobic de-nitrification (bacteria mediated reduction of nitrate to elementary Nitrogen—N_2) takes place in the soil, N_2O is released as a leaking by-product. Both, the nitrogen quantity in circulation and the mean nitrogen turnover rate determine the nitrification and de-nitrification rates and therefore determine the quantity of N_2O released into the atmosphere (besides, of course, the prevailing site characteristics such as waterlogging or temperature or availability of easily degradable carbon sources). The dominant breakdown mechanism of nitrous oxide (to N_2 and O_2) is modulated by ultraviolet solar radiation in the stratosphere. Therefore N_2O, just like all the other GHGs, important in livestock production systems, is a natural substance, which forms part of a natural cycle.

Enteric fermentation normally constitutes an additional source of methane emissions when ruminant livestock is introduced into a pristine ecosystem, unless other sources of methane were displaced (such as wild ungulates) or natural methane emissions were reduced through management interventions such as artificial drainage.

In the case of nitrous oxide, however, the situation is not so clear cut: Grazing animals indeed accelerate nitrogen cycling somewhat; however, they do not increase the amount of nitrogen in circulation. Therefore, nitrous oxide emitted from manure is by no means additionally released by livestock. Herbage and other plant biomass also produce considerable amounts of nitrous oxide (N is mineralized, nitrified and de-nitrified) even without passage through livestock intestines. It could well be that N_2O emission rates from native forests (with often high N content in the leaves) are even greater than from managed grasslands. In this case the 23 kg of CO_2 equivalent per kg carcass weight (emitted as N_2O) charged to the beef industry in South America by Gerber et al. [8] should be reduced to zero or even adopt a negative value, when the grassland is situated at a formerly forested area. This applies even more to grasslands sown with certain species such as *Brachiara* spp. which exert BNI (biological nitrification inhibition) in the rhizosphere, hence considerably reducing N_2O emissions [74]. In any case, this number has to be corrected by the amount of

N_2O that would be released by the pristine ecosystem anyway, even if it had not been altered by management or even if the biomass had not passed through the animal's stomach. On the other hand, the application of nitrogen fertilizer (which is rarely done on extensive grazing land because of economic constraints) certainly increases the chances of N_2O emissions by the elevated quantity of nitrogen in circulation. Nitrogen fertilization is practiced, however, to a far higher degree in (forage) cropping than in true pastoral systems.

The IPCC [60] in its "Guidelines for National Greenhouse Gas Inventories" meticulously provides N_2O emission factors for all the potential sources of nitrous oxide emissions from managed ecosystems, such as total Nitrogen deposited (as fertilizer, cured manure or fresh dung and urine) or mineralized from crop residues or soil organic matter. All the various N_2O sources in managed ecosystems are taken into account by the IPCC, however, no corrections are carried out for emissions from natural baseline scenarios, which would occur anyway in the pristine ecosystems (replaced by the respective agro-ecosystems), even without human intervention. Therefore, net anthropogenic N_2O emissions from managed ecosystems are systematically overvalued.

4. Conclusions

Just like CO_2, non CO_2 GHGs, methane and nitrous oxide, are also part of natural cycles. Rather than considering the actual emissions, one ought to take into account the observed or theoretical difference of atmospheric steady state equilibrium concentrations (between sources and sinks) before and after the creation of a new or additional source of emission which on the other hand might also alter the sink intensity through substrate induced enhanced breakdown rates (auto-catalytic response). If at all, only this difference in the steady state equilibrium concentration of a GHG in the atmosphere could exert any influence on the climate.

CO_2, CH_4 and N_2O concentrations have been increasing in the atmosphere in the past decades [65] most likely due to human activities. However, this trend does not seem to be driven by livestock-born emissions. This can be shown in the case of methane, where no livestock signal is discernible in historical emission rates or in global methane distribution (Sections 3.2.2.1 and 3.2.2.2).

As far as carbon dioxide is concerned, animal husbandry per se is CO_2 neutral (as livestock-born CO_2 emissions by respiration are offset by photosynthesis of herbage regrowth), except for emissions from fossil fuels burned during the production and marketing process, and the one-time emission (or sequestration) from land use change. Fossil fuel consumption is particularly high in intensive factory farming systems with cultivated herbage and grain, transported and fed to animals in confinement, whereas in extensive grazing systems fossil fuel consumption (and the associated CO_2 emission) is very low and can even be zero. For that reason, Ruviaro et al. [75] found the smallest carbon footprint from beef production in grazing systems with fairly high quality forage and therefore, short fattening periods.

Well managed grasslands are stable ecosystems with no net CO_2 emissions and with considerable C storage capacity. Normally, the one-time emission from deforestation for pasture establishment becomes negligible per unit of product once spread out over the accumulated production for the entire period of pastureland utilization (which easily can be hundreds of years). Moreover these emissions have to be corrected by the carbon storage capacity of subclimax grasslands. However, these requirements remain usually disregarded in the scientific practice of emission intensity and life-cycle assessments (emission per kg of product).

As far as non CO_2 GHGs are concerned, baseline emission scenarios over time and space are not taken into account (as shown in sections 3.2.2 and 3.2.3) by (almost?) all the authors of publications on "life-cycle assessments" [37], nor by the IPCC [60] in its "Guidelines for National Greenhouse Gas Inventories" (which most authors refer to). Even the most recent assessment of carbon footprints in different beef production systems in South America [75] does not consider pristine ecosystem or pre-climate change baseline scenarios of GHG-emissions. It is obvious though that the emissions from managed ecosystems need to be corrected by these baseline emissions in order to determine the true anthropogenic part of any "carbon footprint". Therefore, only part of the emissions of non CO_2 GHGs from managed ecosystems can be considered as human induced, i.e. as far as they exceed the natural emissions from the respective pristine ecosystems (now replaced by agro-ecosystems) or from the respective pre-climate-change scenarios. This principle is also recognized by the lead author of the above mentioned paper [75]. It has, however, been overlooked by the IPCC [60] which has been serving as the leading reference for carbon footprint, emission intensity, and life-cycle assessments, hence leading to considerable overestimations of emissions from livestock and cropping. This important methodological deficiency is consistently propagated through recent scientific literature.

Considering all these factors, grass-fed beef should be highly competitive with pork, poultry and any other kind of meat as far as potential climate impact is concerned, even if there were detectable climate sensitivity to anthropogenic greenhouse gas emissions, which is far from certain. The straightforward conclusion from the discussion above is that domestic livestock's and particularly grazing animals' contribution to climate change to any noticeable extent is very unlikely.

Acknowledgments

The author wants to thank Erna Maria Hill, Paraguay, for correcting his rudimentary English, Albert Jacobs, Canada, for providing some complementary ideas, and the "CEA (Concorcio para la Experimentación Agropecuaria)", Paraguay, for contributing substantially to the printing costs.

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