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Methane, nitrous oxide emissions and mitigation strategies for livestock in developing countries: A review

F. Forabosco[1,2#], Zh. Chitchyan[1] & R. Mantovani[2]
[1] Department of Private Husbandry, Armenian National Agrarian University, 74, Teryan, 0009, Yerevan, Armenia.
[2] Department of Agronomy Food Natural Resources Animal Environment, University of Padova, Viale dell' Universita' 16, Agripolis, 35020 Legnaro, Padova, Italy.

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Abstract

Methane (CH_4) and nitrous oxide (N_2O) are two important greenhouse gases (GHGs) that are emitted into the atmosphere by livestock during the process of enteric fermentation and manure management. Developing countries produce a large quantity of those emissions, caused mainly by inefficient animal rearing systems, feed production and manure management. This paper outlines the CH_4 and N_2O emitted from livestock in developing countries and the mitigation actions that could be put in place to reduce atmospheric emissions and increase animal productivity. Emission intensity expresses emission (CO_2 equivalents) per unit of product and describes it in relation to the capacity of local animals to produce from local resources. Developing countries are characterized by low production per animal and, consequently, high emission intensity. The emission intensity of dairy cattle in developing countries ranges from 2 to 9 kg CO_2-eq/kg fat and protein corrected milk (FPCM) and in only a few cases is below 2 kg CO_2-eq/kg FPCM. In sub-Saharan Africa, the average emission intensity is 7.5 kg CO_2-eq/kg FPCM for dairy cattle, 71 kg CO_2-eq/kg of carcass weight for beef cattle, 6.9 kg CO_2-eq/kg FPCM for sheep and goats, and 5 kg CO_2-eq/kg eggs for chickens. Taking into account the limited economic and technical resources in most developing countries, the application of appropriate mitigation tools is recommended to reduce the emissions of CH_4 and N_2O gases in the atmosphere. Increasing livestock productivity through selection and feeding is the most effective tool to reduce emission intensity.

Keywords: Breeding, emission intensity, fermentation, greenhouse gas, manure

Corresponding author: forabosco@yahoo.com

Introduction

In developing countries, the human population is likely to increase to around two billion from now to 2050, as will the livestock sector, with a livestock population of around 34 billion animals by 2050 (Alexandratos & Bruinsma, 2012). In those countries, the numbers of livestock animals are rising to respond to the growing demand for food. Inefficiencies in the livestock systems and low investments in the sector cause the rapid increase of greenhouse gases (GHGs) emitted in the atmosphere (Scholtz *et al*., 2013a).

The list of gases that are considered the main sources of global warming includes carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and other GHGs. At global level, livestock emits in the atmosphere 18% of the total anthropogenic emissions of GHGs. Enteric fermentation and manure represent 80% of the total CH_4 emitted by the agricultural sector and 35 to 40% of total anthropogenic CH_4 emission. Furthermore, livestock activities contribute substantially to the emission of N_2O, accounting for almost two thirds of all anthropogenic N_2O emissions and 75 to 80% of agricultural emissions (Steinfeld *et al*., 2006). In addition, in developing countries the total CH_4 and N_2O emissions will increase in future, mainly because of the expected rise in the number of livestock.

The measure of how much heat these two greenhouse gases could trap in the atmosphere in 100 years is named global warming potential (GWP). For CH_4 and N_2O, GWP is 25 and 298 times greater, respectively, than CO_2. These gases have high capacity to reflect infrared radiation back to earth, the main factor that is responsible for the increase in temperature on earth (Iwata & Okada, 2010; IPCC, 2014).

Greenhouse gasses have been studied extensively in the last decade, but the number of reviews on GHG emissions of livestock in developing countries is limited. To the authors' knowledge, only a few

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emission studies have focused on developing countries in recent years, which are large sources of CH_4 and N_2O emissions and would benefit most from appropriate mitigation actions.

The first section of this paper therefore briefly reviews some complex relations between livestock, methane, and N_2O in developing countries. These have been discussed extensively by Steinfeld *et al*. (2006). For this reason, the authors start from here to investigate new findings in this area that have occurred in the last decade. The second section reviews the literature about CH_4 emission per species in developing countries. Particular attention is dedicated to the species that are most diffuse in those countries. The third section discusses feasible and economically sustainable mitigation strategies that could be put in place in developing countries to reduce GHG emissions and combat climate change.

Methodology

The methodology of this study consists of a literature review in the research fields of methane and N_2O emissions, gas reduction strategies and livestock. The aim of the review is to give the current state of literature in the research fields in developing countries. The literature search was performed in 2016/2017 with the use of Web of Knowledge, Google Scholar, and Scopus. To quantify the emission intensities of ruminants, pigs and chickens in developing countries, the terms 'cattle', 'buffalo', 'sheep', 'goat', 'pig' and 'chicken' were combined with 'climate', 'greenhouse gas', 'methane', 'nitrous oxide' or 'mitigation' and 'developing country' or 'emerging economy'. In addition, the articles included in the review met these inclusion criteria: i) they were published between 2006 and 2017, ii) they were published in the English language, iii) they were peer-reviewed and cited articles, and iv) they referred to developing countries and transition economies. One additional criterion for the comparison of results was that the emission intensity should be expressed in CO_2 equivalents (CO_2-eq) per unit of product (i.e. kg fat and protein corrected milk (FPCM), kg of carcass weight, and kg of eggs). Emission intensity expresses the quantity of gases produced per animal for a unit of production. This measurement reflects most accurately the management, feeding and manure systems of livestock in developing countries and the effects of a given mitigation practice (Hristov *et al*., 2013a). The results were analysed and the conclusions are presented and discussed in this paper critically.

Methane and nitrous oxide emissions in developing countries

Importance of both greenhouse gases

Both CH_4 and N_2O have important effects on the livestock industry in developing countries. International policy discussions have focused in the last two decades on non-CO_2 emissions such as CH_4 and N_2O because these are less expensive to mitigate than CO_2 emissions (Shafer *et al*., 2011; Hristov *et al.,* 2013a). In addition, reduction of CH_4 and N_2O emissions could be economically advantageous for developing countries and environmentally beneficial (Key & Tallard, 2012). Furthermore, CH_4 and N_2O together represent a large quota of GHGs emitted by livestock into the atmosphere, while in non-industrialized countries CO_2 arises mainly from metabolism of plant-derived feedstuffs, and is assumed to be zero, since the CO_2 that is photosynthesized by plants is returned completely to the atmosphere as respired CO_2 (Herrero *et al*., 2011). Lastly, consumers and retailers in developing countries are becoming more aware of the carbon footprint of food and the important positive implication that animals could have on converting human-inedible by-products (e.g. grass) into high-quality human food and products (e.g. milk, meat, wool, and eggs).

Sources of methane and nitrous oxide, enteric and manure emissions

Methane and N_2O are emitted from natural and anthropogenic sources. Natural sources of CH_4 emission represent a small portion of total CH_4 emission in the atmosphere. They are originated mainly by permafrost, termites, oceans, freshwater bodies, gas hydrates, wetlands and non-wetland soils, volcanoes, and wildfires (Kirschke *et al*., 2013). Anthropogenic sources represent a large portion of total CH_4 emission in the atmosphere. They are generated by biomass burning, fossil fuel, cultivations, wastes, and animal husbandry (enteric fermentation and manure management). Enteric fermentation is the process that affects mainly ruminants, and is the result of complex microbiological activity. During this process, which occurs in the rumen in anaerobic conditions, cellulose and other large molecules are broken down, causing the release of hydrogen. Carbon dioxide and hydrogen are converted by methanogenic archaea to methane, which is expelled through the mouth and nose in the process of eructation (Aluwong *et al*., 2011). Methane from manure is generated in anaerobic conditions through a decomposition process of organic matter in faecal and bedding material. The anaerobic environment is a precondition for the production of CH_4 via microbial metabolism of organic material. The manure is degraded into substances such as volatile acids, and these substances are used by bacteria to produce CH_4 (Chadwick *et al*., 2011; Petersen *et al*., 2013).

The emission of N_2O occurs from livestock bedding, solid manure, and surface layers of stored slurry, and in soil after the addition of manure. Most inorganic nitrogen (N) in slurry and fresh solid manure is in the form of ammonium. Transformation from ammonium to nitrate via nitrification is a source of N_2O, as well as the production of NO_3 (nitrate), which is a source of N for the denitrification (the biological reduction of nitrate to N_2 gas) process, which increases further the N_2O production through incomplete denitrification (Chadwick *et al*., 2011; Köster *et al*., 2015). The quantity of CH_4 and N_2O produced by manure is sensitive to environmental conditions such as temperature, manure composition and its management. Correct management of manure together with low temperature can be used as an efficient mitigation tool (Gerber *et al*., 2013a; Petersen *et al*., 2013). In developing countries, the large emitters of CH_4 from enteric fermentation are ruminants (cattle, buffalo, sheep, and goats), while for manure, all domestic species contribute to the production of CH_4 and N_2O (Gerber *et al.,* 2013b).

Projections of methane and nitrous oxide emissions in developing countries

Greenhouse gas emissions from the livestock sector in developing countries continue to rise, and the biggest increase is from CH_4, followed by N_2O (Gerber *et al*., 2013b; Caro *et al*., 2014; Bhatta *et al*., 2015). From 2005 to 2030, CH_4 emissions from enteric fermentation are projected to grow. The developing regions with the largest CH_4 emissions will be Africa (48%), non-OECD (Organisation for Economic Co-operation and Development) Asia (35%), and the Middle East (24%). In the same period, emissions from manure (CH_4 and N_2O) are expected to increase in developing regions by 41%, 38%, 28% and 24% in non-OECD Asia, Africa, Central and South America, and the Middle East, respectively (EPA, 2011). In another study, similar results were found when CH_4 emission was estimated in Africa. In 2000–2030, Herrero *et al*. (2008) estimated an average increase of 40% in CH_4 emission. By 2030, CH_4 emission is likely to have increased by 79%, 69%, and 16% in West Africa, Southern Africa, and Central Africa, respectively. In a fifty-year study, the analysis of CH_4 emissions in developing regions has shown an increase, particularly in more recent years (Caro *et al*., 2014). Total CH_4 emissions in Africa, Central, South America, the Middle East, and non-OECD Asia was 56% in 1990, 54.7% in 2010, and will increase to 66.8% in 2030, with the small decrease in 2010 because of the world financial banking crisis, which started in 2008 and affected all sectors, including livestock production in developing countries (Török *et al*., 2015). Caro *et al.* (2014) analysed N_2O emissions in developing countries between 1961 and 2010, highlighting an increase of N_2O from 307.5 Mt CO_2-eq to 701.96 Mt CO_2-eq with positive trends for the years afterwards.

Emissions per species

Dairy cattle

The demand for dairy products in developing countries is increasing, but the level of dairy cattle productivity is relatively stable, and ranges between 1300 and 5000 kg milk per milking cow per year (Alexandratos & Bruinsma, 2012). For this reason, to compensate for the growing demand for dairy products, the number of dairy cattle is increasing. In industrialized countries, the situation is the opposite, because productivity per animal has increased constantly in the last 30 years, owing to a continual improvement in breeding, feeding, and management (Nicolazzi *et al*., 2011; Lehrman *et al*., 2014), and the number of dairy cattle is decreasing. A study conducted by Opio *et al.* (2013) investigated the gas emissions per unit of milk produced in various countries, and identified large differences in developing regions, ranging from 2 to 9 kg CO_2-eq/kg of FPCM. In sub-Saharan Africa, South Asia, and NENA (Near East and North Africa), GHG emissions were on average 7.5, 4.6, and 3.7 kg CO_2-eq/kg FPCM at farm gate, respectively (Gerber *et al.*, 2010). In a simulation study in Armenia, a developing country in East Europe, the emissions from improved dairy cattle were 2.4 kg CO_2-eq/kg of milk at 16 °C, a value between that of the emissions of developed countries in East Europe and the developing countries of the Middle East (Forabosco *et al*., unpublished). Similar results were obtained in the district of Amend (India), where the carbon footprint of milk production under the smallholder dairy system was 2.2 kg CO_2-eq/kg FPCM (Garg *et al*., 2016). In a lifecycle assessment study (cradle to farm gate) of smallholder dairy cattle farms in India using a large dataset and comparing two levels of feeding management (no improvement vs improvement of feeding), Garg *et al.* (2014) found a reduction of emission intensity from 1.8 (with no feeding improvement) to 1.2 kg CO_2-eq/kg FPCM (accounting for feeding improvement), clearly indicating that correct and balanced feeding has a positive effect on reducing gas emissions. Gerber *et al.* (2011) pointed out that for cows producing up to 1000 kg FPCM, the incidences of CH_4 and N_2O on total gas emissions are 52% and 42%, respectively. With productivity between 1001 and 3000 kg FPCM the incidence of CH_4 and N_2O is reduced to 50% and 32%, respectively, and from 3001 to 5000 kg FPCM it is further lowered to 47% and 26%, respectively. Furthermore, CH_4 and N_2O emissions decrease with the increase of milk productivity and at up to 2000 kg FPCM/cow/year the emissions ranged from 12 kg CO_2-eq/kg FPCM to about 3 kg CO_2-eq/kg FPCM, while at around 6000 kg FPCM/cow/year the emission was stabilized between 1.6 and 1.8 kg CO_2-eq/kg FPCM, similar to the trend found by Garg *et al.* (2014). In addition, management systems play an important role in CH_4 and N_2O emissions in developing counties. Extensive dairy production systems (i.e. pasture) have the highest emissions, while intensively managed dairy production systems have the lowest (Du Toit *et al*., 2013; Scholtz *et al.*, 2013c; Knapp *et al*., 2014). In South Africa, Meissner *et al.* (2013a) found that in 2007 the emission intensity of CH_4 from dairy cows not in milk recording (average production of 4590 kg milk per cow) and in milk recording (average production of 6950 kg milk per cow) were 1.6 and 1.4 CO_2-eq/kg of milk, respectively. Neither emission intensity included N_20 emission nor the milk was corrected for the contents of fat and protein. In a lifecycle assessment study conducted in smallholders dairying in Kenya, it was found that the average emission intensity for milk production was 2.0 kg CO_2-eq/kg FPCM (Weiler *et al.*, 2014), while in another lifecycle assessment study conducted in Iran, values were low and ranged between 1.57 kg CO_2-eq/kg FPCM at farm gate and 1.73 kg CO_2-eq/kg FPCM at the milk processing gate. Differences between the two lifecycle assessment studies were mainly the result of differences in environment, feeding and management systems (Daneshi *et al*., 2014). Table 1 summarizes the emissions for the most common species raised in developing countries and regions.

Beef cattle

Beef cattle have the highest emission intensity in developing countries (Gerber *et al.*, 2013b; Caro *et al.*, 2014; Patra, 2014). In those countries, total emissions from beef cattle almost doubled in four decades, from 663.95 MtCO_2-eq in 1961 to 1286.60 MtCO_2-eq in 2010, while the emissions per ton of meat decreased from 75.37 (t CO_2-eq/ton of product) in 1961 to 35.48 (t CO_2-eq/ton of product) in 2010 (Caro *et al.*, 2014). In particular, beef production has the highest emission intensities in South Asia (76 kg CO_2-eq/kg carcass weight (CW), Latin America and the Caribbean (72 kg CO_2-eq/kg CW), and sub-Saharan Africa (71 kg CO_2-eq/kg CW), and the lowest, only 48 kg CO_2-eq/kg of CW, in East and South-East Asia (Gerber *et al.*, 2013b). In those regions, there is a difference in emission intensity between beef produced from dairy herds and that from specialized beef herds. The emission intensity of beef from specialized beef herds is almost fourfold that produced from dairy herds (68 vs 18 kg CO_2-eq/kg of CW) because in specialized beef herds, the main production is meat, and all emissions are allocated to meat, while in dairy herds milk is the primary output and meat the secondary output, thus emissions are shared between the two outputs (Gerber *et al.*, 2013b). The extensive beef management system uses large quantities of forage that increase gas emissions (Du Toit *et al.*, 2013). In addition, the reproduction efficiency of cows in developing countries is low owing to nutrition and management problems, and this affects the emissions negatively. Furthermore, the health conditions of the animals play an important role because sick animals and animals affected by subclinical diseases have low production and thus the emissions per unit of product increases (Meissner *et al.*, 2013a).

In a study conducted in Brazilian beef farms, CH_4 from enteric fermentation was the most abundant source of gas, with 75% of total emissions when the meat cycle was analysed from cradle (in Brazil) to final market (Europe). At farm gate (not including emissions from land use changes) the emission intensity was 28 kg CO_2-eq/kg of CW. The slaughter and transport of beef carcasses (free of bones where 1kg CW= 0.7 kg bonefree CW) from Brazil to Europe (Stockholm) was 41 kg CO_2-eq/kg bonefree CW (Cederberg *et al.*, 2009). In Brazil, another study conducted in intensive farm systems with less than 2000 head per farm found emission intensity ranged from 4.8 to 8.2 kg CO_2-eq/kg of live weight gain (from 9.0 to 15.5 kg CO_2-eq/kg CW), while for the farms with more than 2000 head the range was between 5.0 and 7.2 kg CO_2eq/kg of live weight gain (from 9.4 to 13.5 kg CO_2-eq/kg CW). Values were low compared with the previous work owing to a partial lifecycle assessment, lack of consistency between boundaries, and differences in functional unit and time scale (Cerri *et al.*, 2016). In Argentina, one of the large beef cattle countries, in which the majority of animals are raised on grass-based systems, CH_4 emission intensity ranged from 37 kg CO_2-eq/kg CW (year 2008) to 40 kg CO_2-eq/kg CW (year 2010). The values were somewhat high compared with results from previous years owing to lower production efficiency caused by forage shortage in a long-lasting drought (Rearte & Pordomingo, 2014).

Buffalo

Buffalo populations are present all over the world, but they are largely diffuse in developing countries in Asia and Africa, where the meat and milk play an important role in feeding the local populations (Wanapat & Kang, 2013; Cawthorn & Hoffman, 2014). Most buffalo milk (80%) is produced in mixed systems in semi-arid climates. Milk emission intensity was estimated at 3.2 kg CO_2-eq/kg FPCM in South Asia, 3.7 kg CO_2-eq/kg FPCM in Near East and North Africa, and 4.8 kg CO_2-eq/kg FPCM in East and South-East Asia. Emission intensity of buffalo meat production has broad variations, ranging from 21 kg CO_2-eq/kg CW in Near East and North Africa to 70.2 kg CO_2-eq/kg CW in East and South-East Asia. The large variations are due to the quality of feed, different management systems and local climatic conditions (Gerber *et al.*, 2013b).

Table 1 Literature review of greenhouse gas emissions in developing countries[a]

Species	**GHG emission in kg CO_2-eq kg-product^{-1}**	**Developing country/region**	**System boundary**	**Reference**
Dairy cattle	7.5	Sub-Saharan Africa	Farm gate	Gerber *et al*., 2010
	4.6	North Africa	Farm gate	Gerber *et al*., 2010
	3.7	Near East	Farm gate	Gerber *et al*., 2010
	2.4	Armenia	Farm gate	Forabosco *et al*., unpublished
	2.2	India	Farm gate	Garg *et al*., 2016
	2.0	Kenya	Farm gate	Weiler *et al*., 2014
	1.8	India	Farm gate	Garg *et al*., 2014
	1.73 & 1.57	Iran	Milk proc. Gate & Farm gate	Daneshi *et al*., 2014
Beef cattle	76	South Asia	Farm gate	Gerber *et al*., 2013b
	72	Latina America and Caribbean	Farm gate	Gerber *et al*., 2013b
	71	Sub-Saharan Africa	Farm gate	Gerber *et al*., 2013b
	69	Brazil	County of destination	Cederberg *et al*., 2009
	48	East and South East Asia	Farm gate	Gerber *et al*., 2013b
	37–40	Argentina	n.a.	Rearte & Pordomingo, 2014
	28[b]	Brazil	Farm gate	Cederberg *et al*., 2009
Buffalo (milk)	5.0-5.8	North Africa	Farm gate	Opio *et al*., 2013
	4.8	East Asia	Farm gate	Gerber *et al*., 2013b
	4.8	South-East Asia	Farm gate	Gerber *et al*., 2013b
	3.7	Near East	Farm gate	Gerber *et al*., 2013b
	3.7	North Africa	Farm gate	Gerber *et al*., 2013b
	3.2	South Asia	Farm gate	Gerber *et al*., 2013b
	2.6–2.7	Near East	Farm gate	Opio *et al*., 2013
	2.5–3.0	India	Farm gate	Garg *et al*., 2016
	1.3–1.4	India	n.a.	Patra, 2012
Sheep and goats	29.0[d]	South Asia	Farm gate	Opio *et al*., 2013
	27.9[d]	Near East and North Africa	Farm gate	Opio *et al*., 2013
	25.5[d]	Latin America	Farm gate	Opio *et al*., 2013
	23.0[d]	East and Southeast Asia	Farm gate	Opio *et al*., 2013
	19.0[d]	New Zealand	Farm gate	Ledgard *et al*., 2011
	9.3–11.2[c]	Near East and North Africa	Farm gate	Opio *et al*., 2013
	8.9[c]	East and South-East Asia	Farm gate	Gerber *et al*., 2013b
	8.7[c]	Near East and North Africa	Farm gate	Gerber *et al*., 2013b
	6.9[c]	Sub-Saharan Africa	Farm gate	Gerber *et al*., 2013b
	5.5–9.6[c]	Latin America and Caribbean	Farm gate	Opio *et al*., 2013
	4.9[c]	South Asia	Farm gate	Gerber *et al*., 2013b
Pigs	6.0–7.1	Developing regions	Farm gate	Gerber *et al*., 2013b
	6.0–6.7	China	Farm gate	Mottet *et al*., 2017
	5.8–6.8	Vietnam	Farm gate	Macleod *et al*., 2013
	5.5–6.9	Developing regions	Farm gate	Macleod *et al*., 2013
Chicken	6.2[e]	East and South-East Asia	Farm gate	Gerber *et al*., 2013b
	5.0[e]	Sub-Saharan Africa	Farm gate	Gerber *et al*., 2013b
	3.5[e]	Near East and North Africa	Farm gate	Gerber *et al*., 2013b
	3.2[e]	Latin America and the Caribbean	Farm gate	Gerber *et al*., 2013b
	2.7[e] & 6.2[d]	South Asia	Farm gate	Gerber *et al*., 2013b
	5.8[d]	East and South-East Asia, Near East and North Africa	Farm gate	Gerber *et al*., 2013b

[a] For easy comparison, only data expressed in the same unit of measurement (kg CO_2-eq/kg FPCM (fat and protein corrected milk) or CW (carcass weight) or eggs) are presented, [b] Not including the land use change emissions, [c] Milk
[d] Meat, [e] Eggs. n.a: not available

In the same region, Opio *et al.* (2013) found broad variations in emission intensities. In mixed dairy buffalo systems in arid zones in Near East and North Africa, emissions can vary between 2.6 and 5.8 kg CO_2-eq/kgFPCM, respectively. In the same region and agro-ecological zone, but in a different system (grassland dairy buffalo system), emissions can vary between 2.7 and 5.0 kg CO_2-eq/kg of FPCM. A lifecycle assessment (cradle to farm gate) in India estimated that the emissions from buffalo milk ranged from 2.5 to 3.0 kg CO_2-eq/kg of FPCM, and that the contribution of CH_4 and N_2O on emission from buffalos accounted for 80.5% and 11.3%, respectively, of total farm emissions (Garg *et al.*, 2016). Similar results were confirmed by (Garg *et al.*, 2014)for buffalo in India, where the enteric and manure emissions of CH_4 and manure management emission of N_2O were 71.6%, 7.4%, and 12.6%, respectively. Patra (2012), in a study of dairy buffalos in the same country using 2003 and 2007 data, estimated the emissions to be equal to 1.4 and 1.3 kg CO_2-eq/kg FPCM, respectively. In a different study in India, Chhabra *et al.* (2013) found that buffalo had a lower contribution of enteric CH_4 emission, which was 42% of total enteric emission, and the CH_4 emission from manure management accounted for 9.3% of the total livestock CH_4 emissions. Chhabra *et al.* (2013) found total CH_4 emission from buffalo in India of 51.3%, lower than the value found by Garg *et al.* (2014) and Garg *et al.* (2016), but differences are due mainly to differences in the datasets.

Sheep and goats

Small ruminants in developing countries represent an important economic resource for local communities (Tindano *et al.*, 2015; Yogi *et al.*, 2015). In the regions where large populations of sheep and goats are raised in East and South-East Asia, Near East and North Africa, sub-Saharan Africa and South Asia, emission intensities for milk are 8.9, 8.7, 6.9, and 4.9 kg CO_2-eq/kg FPCM, respectively (Gerber *et al.*, 2013b). South Asia showed the lowest emission intensity in developing regions because the productivity of small ruminants is relatively high compared with other regions. Goat milk tends to have lower emission intensity compared with sheep milk in the same developing region owing to its high productivity. Large differences in emission can be observed in developing regions in relation to different agro-ecological zones and systems. For example, in arid zones of Near East and North Africa, emission intensity can range between 9.3 and 11.2 kg CO_2-eq/kg FPCM in grassland and mixed systems, respectively. In humid regions of Latin America and the Caribbean, the variations between systems are even larger (9.6 and 5.5 kg CO_2-eq/kg FPCM in grassland and mixed systems, respectively) and are caused by differences in feed quality and productivity of the animals (Opio *et al.*, 2013). In West Africa, Gerber *et al.* (2013b) and Mottet *et al.* (2016) found for milk produced by small ruminants an emission intensity of 8.2 kg CO_2-eq/kg FPCM, which is 20% higher than the global average of 6.8 kg CO_2-eq/kg FPCM. This phenomenon can be related to low productivity owing to lower feed digestibility (average feed digestibility of 55%, in comparison with the global average of 59%), poor animal health (mortality rates for adult and young animals were 9.5% and 26%, respectively, compared with global average rates of 8.8% and 20.6%, respectively), and poor breeding (absence of selection plans). Emission intensity of meat from small ruminants has small variations among developing regions of the world. In East and South-East Asia, Latin America, Near East and North Africa, and South Asia, intensities are 23.0, 25.5, 27.9, and 29.0 kg CO_2-eq/kg CW, respectively (Opio *et al.*, 2013). In a lifecycle assessment of lamb meat for export in New Zealand, Ledgard *et al.* (2011) found an average emission intensity of 19 kg CO_2-eq/kg of lamb meat. In this investigation, the authors found that 80% of the emissions are produced within the farm (mainly CH_4 and N_2O), 3% from processing, 5% from transportation and 12% from retail and home cooking.

Pigs

At global level, over half of total CH_4 emissions are from non-ruminants, and pigs play a fundamental role (O'Mara, 2011). In 2010, pig emissions were about the same in developed and developing countries., In 1992–2010 pig emissions in transition economies declined by 4.4% per year (Caro *et al.*, 2014). In developing regions, emission intensity was greater, and ranged between 6.0 and 7.1 kg CO_2-eq/kg CW. Latin American and Caribbean regions had the highest emission with 7.1 kg CO_2-eq/kg CW, followed by East and South-East Asia, with 6.0 kg CO_2-eq/kg CW. Large differences could be found among production systems, and the backyard system had the lowest emissions compared with industrialized and intermediate systems. However, the backyard system is characterized by relatively high manure emissions (CH_4 and N_2O) caused by low-quality feed (Gerber *et al.*, 2013b). The results were confirmed by Macleod *et al.* (2013), who found in developing regions less emission intensity (5.5-6.9 kg CO_2-eq/kg CW) for the backyard system than for the intermediate and industry systems. In China, animal farming is a significant source of GHG emissions into the atmosphere owing to the large number of pigs and the great emissions of NH_3 (ammonia) and N_2O in the environment (Gao *et al.*, 2013). In a different study, Mottet *et al.* (2016) pointed out that pig production has increased in China in the last three decades, mostly in the intermediate and industrial systems, and now accounts for 30% and 40% of total production, respectively, of the entire east and southeast region. The authors estimated that the emission intensity was 6.7 kg CO_2-eq/kg CW for intermediate pig production systems and 6.0 kg CO_2-eq/kg CW for industrial pig production systems. In Vietnam, using a Monte Carlo analysis, the intensity of emissions for backyard and intermediate systems for pigs was estimated at 6.8 and 5.8 kg CO_2-eq/kg CW, respectively, and results were similar to previous studies (Macleod *et al.*, 2013).

Chicken

Poultry contributes significantly to manure management emissions, which drive increases in N_2O emissions because of the relatively high nitrogen content of poultry waste and the manure management systems (EPA, 2011). In developing countries there are three types of chicken production systems: backyard layers, industrial layers (both are for meat and eggs), and industrial broilers (only meat). The most common system in marginal and poor areas of non-industrialized countries is the backyard system (Sarwar *et al.*, 2015), which is characterized by high emission intensity caused by poor feed conversion ratios, high proportion of unproductive animals, high mortality and low fertility rates (Gerber *et al.*, 2013b). Chickens for meat production in general have high emission intensity compared with egg production, because more feed is required to produce 1 kg meat compared with 1 kg eggs. The emission intensity of chicken egg production in developing regions was 6.2 kg CO_2-eq/kg eggs in East and South-East Asia, 5 kg CO_2-eq/kg eggs in sub-Saharan Africa, 3.5 kg CO_2-eq/kg eggs in Near East and North Africa, 3.2 kg CO_2-eq/kg of eggs in Latin America and the Caribbean, and 2.7 kg CO_2-eq/kg eggs in South Asia. The highest value of emissions in East and South-East Asia were caused mainly by moderate feed emission intensity and high anaerobic activity of manure storage (Macleod *et al.*, 2013). For chicken meat production, Garber *et al.* (2013a) found a small variation among developing regions with an average emission intensity ranging from 6.2 kg CO_2-eq/kg of CW in South Asia to 5.8 kg CO_2-eq/kg of CW in East and South-East Asia, Near East and North Africa. The range of emissions among developing regions is therefore very close, indicating that production systems and the level of technology are at similar levels. In India, it was estimated that the total N_2O emission of Indian livestock in 2003 was equal to 1.42 Gg/year. The major contribution of N_2O, at 86.1%, was from poultry, while the contribution of CH_4 was marginal (Chhabra *et al.*, 2013).

Methane and nitrous oxide mitigation strategies from a livestock prospective

The main aim of CH_4 and N_2O mitigation strategies involves actions that limit the magnitude of negative long-term effects of climate change. Mitigation generally involves reductions in livestock emissions (e.g. respiration and manure) and anthropogenic emissions linked with livestock activities (e.g. fodder production, crop processing, and manure distribution). Mitigation may also be achieved by increasing the capacity of carbon sinks, (e.g. through restoration of degraded soils, and reforestation) and through correct long-term sustainable policies that reduce the risks associated with human-induced global warming. However, mitigation strategies in developed countries are not always feasible and economically sustainable for developing countries. In this section, the authors discuss sustainable mitigation strategies for the reduction of CH_4 and N_2O emissions in livestock focusing on three areas: selection, feeding, and management.

Selection

In developing countries, measuring CH_4 and N_2O emissions directly from animals is not always feasible owing to high costs and the need for expensive infrastructure such as respiration chambers. In future, when the costs of genomic selection will be more affordable for breeding organizations in transition economies, it may be possible to genotype breeding animals and estimate genomic breeding values for CH_4 and N_2O emissions. In industrialized countries, genomic selection is a reality (Hayes *et al.*, 2013; Pickering *et al.*, 2015a; Pickering *et al.*, 2015b; Meuwissen *et al.*, 2016), but in developing countries it is not yet disseminated (Scholtz *et al.*, 2010). One of the major issues is the costs associated with the measurement of CH_4 and N_2O emissions and genotyping of a large sample of animals (reference population). The great advantage of this method is that when the equations that predict genomic breeding values from SNPs (single nucleotide polymorphisms) are estimated on the reference population, they can then be used to predict genomic breeding values (GBV) for selection candidates based on their genotypes alone without the need to collect phenotypic data and with good accuracy of GBV (Calus *et al.*, 2013). Alternatively, when direct measures of CH_4 and N_2O cannot feasibly be applied to enough animals to establish a reference population, genomic selection can be based on correlated traits such as dry matter intake and other proxies. While there is evidence that there are correlated and predictor traits for CH_4 and N_2O emissions, the current level of knowledge is insufficient to recommend their use in selection to reduce these gases (Pickering *et al.*, 2015b). In developing countries, where genetic selection is already in place, CH_4 emission from enteric fermentation could be reduced by including in the total merit index (TMI) traits that reduce mortality (such as fertility, longevity, and animal health) and increase the number of productive animals (Meissner *et al*., 2013a). More fertile females, healthy, and with good longevity, can have more offspring. Thus, their feed requirements and gas emissions are diluted over this increased number of offspring. Furthermore, in those countries where protein for human consumption is a priority and productivity of animals is low, selection to increase the quantity of product per animal (e.g. meat, milk, eggs, and wool) should be maintained. Eventually the weight of this trait in the TMI should be increased. With the increase of productivity per animal, total CH_4 and N_2O emissions may increase, but emission intensity would be reduced, because the total emissions would be diluted over an increased quantity of product. Genetic improvement of indirect traits, such as feed conversion efficiency, plays an important role in the reduction of emissions for all livestock species, and is particularly important in swine and chicken. Those species have little contribution to enteric CH_4 emission as most CH_4 and N_2O are caused by manure storage and land application. Thus, genetic improvement of feed conversion efficiency reduces the total manure produced and consequently reduces the emissions of CH_4 and N_2O while maintaining productivity (Hristov *et al.*, 2013a). In dairy and beef cattle, genetic selection for residual feed intake has shown that this indirect approach to reducing CH_4 emission is moderately heritable (0.26 to 0.43) and moderately repeatable across diets (0.33 to 0.67), indicating that the inclusion of this trait in the TMI could effectively reduce CH_4 emissions (Basarab *et al.*, 2013). In developing countries, where economic resources for selection are insufficient, CH_4 and N_2O emission reduction from enteric and manure fermentation can be achieved with the financial support of international donors (Arakelyan & Moran, 2015; Samaniego & Schneider, 2015) and with the aggregation of countries that have similar selection interests. Aggregation of countries could reduce selection costs per country, increase the number of potential candidates, select for animals that have high performance (i.e., high productivity, low mortality rate, better health), and generate profit with the commercialization of genetic material (i.e. offspring, semen and embryos) of superior animals. Furthermore, the use of local genetic resources in poor countries with extreme environmental conditions (i.e. hot or harsh environments) represents a better solution than importing highly improved animals that cannot perform as expected because of environmental constraints (Boettcher *et al*., 2015). On the opposite side, for developing countries with an environment similar to Europe and North America, the use of exotic breeds (European and American) instead of local genetic resources could represent an efficient economic solution (Kavoi *et al.*, 2010) and have a positive effect on reducing GHG emissions (Mushi *et al.*, 2015). In intermediate climate conditions, such as South Africa, crossbreeding could be a sustainable solution to mitigating gas emission (Scholtz *et al*., 2012; Mokolobate *et al*., 2014). In this country, 67% of feedlot cattle are crossbreeds from indigenous Sanga and exotic breeds aimed at increasing meat production and adaptability and reducing CH_4 emissions. The use of two-breed and three-breed crosses of indigenous and exotic breeds increases productivity owing to the heterosis effect and reduces the CH_4 emission per unit of product (Scholtz *et al.*, 2013b). However, it is important to ensure that the indigenous breeds are properly conserved (Boettcher *et al*., 2015) to guarantee the availability of purebred animals and provide sustainable food for local populations (Meissner *et al*., 2013b; Rust & Rust, 2013). In India and other developing countries, where, for religious reasons, cattle are not slaughtered, if available, the use of sexed semen could be a sustainable solution to reducing the number of unproductive cattle, and this technology could have the positive effect of reducing CH_4 and N_2O emissions (Hristov *et al.*, 2013b). In developing countries, where genetically modified animals (GMA) are authorized, the use of environmentally friendly GMA is an option that should be investigated (Forabosco *et al.*, 2013).

Feeding

In developing countries, an important mitigation option for livestock, in particular ruminants, is the utilization of forages of higher digestibility. This aspect is particularly important in those countries where the digestibility of forages in general is limited owing to high amounts of lignin because of incorrect management of agronomical practices. When the digestibility of forages increases, enteric fermentation and manure production are reduced, and consequently the emissions of CH_4 and N_2O decrease. For example, when legume silage replaces grass silage in the diet, because of the lower fibre content and the presence of high digestible organic nitrogen, CH_4 and N_2O emissions are reduced (Hristov *et al.*, 2013a). Smallholders in mixed crop livestock systems in Africa and Asia are characterized by livestock herds with many unproductive animals, small quantities of high-quality feed and large quantities of low-quality feed. An effective mitigation strategy is to reduce the number of animals (keeping only the best animals) and provide feed with higher digestibility, reserving the low-quality feed for other purposes (e.g. bedding). This strategy would increase productivity and reduce CH_4 and N_2O emissions. However, this mitigation option is in conflict with the interests of smallholders, who want to have large unproductive herds for social and risk mitigation reasons. Regulatory measures (policy and quota systems), economic incentives (micro credits and loans in kind), and change in social behaviours (social disincentives) could reduce the benefits of keeping unproductive animals and support the intensification of livestock production (Udo *et al.*, 2011; Haileslassie *et al.*, 2016). In a study in India, important mitigation measures for livestock are improving feed by adding digesters and CH_4 inhibitors and enhancing the number of crossbred animals that have lower CH_4 emissions per unit of production (Garg *et al.*, 2011). In poor economies, urea is used extensively to improve low-quality feed. It is mixed with fodder (e.g. straws and crop residuals) at least one week prior to use. During this period ammonia is formed, which breaks the cell walls and allows the microorganisms in the rumen to metabolize the organic material in the cells, improving feed intake and digestibility. In addition, urea provides N, which improves the feed value (Dawit *et al.*, 2015). A good mitigation option, but less feasible in developing countries, is the use of concentrate feeds in the animal's diet. Concentrates are rich in lipids (oils) and other substances with high levels of energy (e.g. cereal grains). The inclusion of concentrate feeds in the diet of ruminants and non-ruminants could reduce CH_4 emission intensity (Herrero *et al.*, 2016), but the possibility of using this mitigation tool in poor economies depends on costs and availability. Forage processing, such as the mechanical reduction in size of forages, increases digestibility, feed intake and animal productivity, and could be considered an effective enteric CH_4 mitigation practice in poor economies (Makkar, 2016). Correct pasture management, crop rotation and an intensive grazing system could be important mitigation practices that could guarantee more efficient conversion of forage into economic products and result in CH_4 and N_2O emission reduction (Gerber *et al.*, 2013a; Havlík *et al.*, 2014). Other technical mitigation options (Gerber *et al.*, 2013a; Erasmus & Webb, 2014; Herrero *et al.*, 2016; Elghandour *et al.*, 2016), such as the use of feed additives (electron receptors, ionophore antibiotics, enzymes and probiotics), vaccines and precision feeding, are not available or only partially available in marginal economies. Their availability and use are limited because of high costs, limited accessibility, policy limitations, lack of technology, and lack of breeders' specific knowledge.

Management of manure

In developing countries, manure and slurry are not always considered valuable resources, and unmanaged accumulation of animal waste represents a source of gas emissions and a health threat for animals and humans. Unmanaged manure and slurry can cause eutrophication and contamination of surface water, leaching of nitrates, degradation of natural resources and GHG in the form of CH_4 and N_2O (direct and indirect emissions), NH_3, and other toxic gases (Hristov *et al.*, 2013a). In Africa, the management of manure depends largely on the livestock management system: in the extensive rangeland system, manure is not managed, while in the mixed system, manure is applied only partially to grazing land, and in the industrial system it is applied mainly to high-value crops such as coffee, tea, and tobacco (Herrero *et al.*, 2013). Furthermore, in both extensive and intensive grazing systems, where N concentrations per hectare are high, large N losses occur through leaching and volatilization from point sources of urine and solid manure (Petersen *et al.*, 2013). In Asia, manure is considered a valuable resource, and is used as organic fertilizer, in biogas production, and as biofuel. In Latin America, recycling of manure is not diffuse owing to availability of cheap industrial fertilizer, deforestation and subsequent expansion of agriculture on fertile land, and a rotation system with the possibility of letting the soil regenerate for a few years (Thien Thu *et al.*, 2012; Herrero *et al.*, 2013). Large differences in manure management can be seen between countries in the same continent. This depends mainly on the farmers' knowledge, financial state support (for biogas production, construction of modern lagoons for slurry, machineries for the distribution of manure, etc.) and national policies (Jiang *et al.*, 2011; Teenstra *et al.*, 2014). Correct management of manure has been extensively demonstrated to be the most important tool that can minimize losses due to CH_4 and N_2O volatilization and runoff (Petersen *et al.*, 2013; Sommer *et al.*, 2013). Manure from ruminants and non-ruminants can be treated by various methods for improved handling, nutrient use and energy generation. In developing countries, simple techniques such as piling, compacting and covering the manure have positive effects on reducing emissions and nutrient losses. For example, covering solid manure with straw or plastic sheets reduces, in general, both CH_4 and N_2O emissions, whereas covering liquid manure stores is adopted mainly to reduce NH_3 emissions (Petersen *et al*., 2013). N_2O emissions from liquid slurry are minimal during storage, unless a surface crust is present (VanderZaag *et al*., 2009). In sub-Saharan Africa, the production of compost in pits with a mix of animal faeces, feed and crop residues and domestic waste is extensively prevalent among small households. Householders irrigate the pit, turn the compost, use a cover to limit N losses, and use the compost as natural fertilizer, because it is particularly rich in nutrients (Smith *et al.*, 2014). In Vietnam, parts of both liquid and solid manure produced by pig farms are applied to fish ponds and used to feed fish for local consumption (Vu *et al.*, 2012). Modern technology, such as manure separation, anaerobic digestion, aeration, use of additives and inhibitors (Petersen *et al*., 2012; Zaman & Nguyen, 2012; Gebrezgabher *et al.*, 2015; Kinyua *et al.*, 2016), to treat manure and slurry from ruminates and non-ruminants, may not represent a feasible option to reduce GHG emissions in developing countries. The main reasons are high costs, low accessibility, high technology required, lack of knowledge, and insufficient legislation.

Conclusions

This review investigated CH_4 and N_2O emissions from livestock and mitigation actions in developing countries. The results indicate that emission intensities from livestock are medium to high in poor countries owing to low animal productivity, low feed quality, lack of knowledge, and limited investments. There are differences among developing countries in animal gas emissions in the same continent or region, indicating that improvements are possible. The countries with lowest livestock gas emissions should be the drivers of improvement of all other countries in the same region or continent. Developing countries should promote production systems with low emission intensity (chicken meat, eggs, cow milk and pork meat) or medium emission intensity (meat and milk from small ruminants), and the international community should support modernizing and improving the efficiency of productions with the higher emission intensity (meat from beef cattle). Mitigation tools to reduce CH_4 and N_2O emissions that are used in industrialized countries are not always applicable to developing countries. Developing countries must use the mitigation tools adaptable to their conditions, considering the costs, knowledge, applicability, and local legislation. In the future, interdisciplinary research should focus on the integration of livestock emissions at country level and sustainable mitigation and adaptation tools that could be applied at local levels.

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Authors' Contributions

FF designed the study, wrote the manuscript and reviewed the manuscript critically for important climate change issues. ZC carried out the manuscript writing, and RR drafted and reviewed the manuscript critically for important livestock issues and gave the final approval of the version for publishing.

Conflict of Interest Declaration

The authors declare that they have no affiliations with any organisation or entity with any financial or non-financial interest that could bias the subject matter and outcomes discussed in this manuscript.

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