Chapter 11

# Livestock as Sources of Greenhouse Gases and Its Significance to Climate Change

Veerasamy Sejian, Raghavendra Bhatta, Pradeep Kumar Malik, Bagath Madiajagan, Yaqoub Ali Saif Al-Hosni, Megan Sullivan and John B. Gaughan

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/62135

**Abstract**

This chapter outlines the role of livestock in the production of greenhouse gases (GHGs) that contributes to climate change. Livestock contribute both directly and indirectly to climate change through the emissions of GHGs such as carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$). As animal production systems are vulnerable to climate change and are large contributors to potential global warming, it is vital to understand in detail enteric $CH_4$ emission and manure management in different livestock species. Methane emissions from livestock are estimated to be approximately 2.2 billion tonnes of $CO_2$ equivalents, accounting for about 80% of agricultural $CH_4$ and 35% of the total anthropogenic $CH_4$ emissions. Furthermore, the global livestock sector contributes about 75% of the agricultural $N_2O$ emissions. Other sources of GHG emission from livestock and related activities are fossil fuels used for associated farm activities, $N_2O$ emissions from fertilizer use, $CH_4$ release from the breakdown of fertilizers and from animal manure, and land-use changes for feed production. There are several techniques available to quantify $CH_4$ emission, and simulation models offer a scope to predict accurately the GHG emission from a livestock enterprise as a whole. Quantifying GHG emission from livestock may pave the way for understanding the role of livestock to climate change and this will help in designing appropriate mitigation strategies to reduce livestock-related GHGs.

**Keywords:** climate change, enteric methane, GHG, livestock, manure management, modeling

## 1. Introduction

The Intergovernmental Panel on Climate Change (IPCC), convened by the United Nations, has reported evidence that human activities over the past 50 years have influenced the global climate through the production of GHG [1]. Increasing concentrations of GHGs in the atmosphere have contributed to an increase in the Earth's atmospheric temperature, an occurrence known as global warming [2]. Indeed, average global temperatures have risen considerably, and the IPCC [1] predicts increases of 1.8–3.9ºC (3.2–7.1ºF) by 2100. With business as usual, Earth's temperature may rise by 1.4–5.8ºC by the end of this century, and the scientific community warns of more abrupt climatic change in the future [3].

The livestock sector accounts for 40% of the world's agriculture gross domestic product (GDP). It employs 1.3 billion people and creates livelihoods for one billion of the world's population living in poverty [2]. As animal production systems are vulnerable to climate change and are large contributors to potential global warming through methane ($CH_4$) and nitrous oxide ($N_2O$) production, it is vital to understand in detail enteric $CH_4$ emission and manure management in different livestock species [4]. Before targeting GHG reduction strategies from enteric fermentation and manure management, it is important to understand the mechanisms of enteric $CH_4$ emission in livestock, the factors influencing such emission. In addition, an understanding of the available prediction models and estimation methodology for quantification of GHGs is essential. A thorough understanding of these will in turn pave way for formulation of effective mitigation strategies for minimizing enteric $CH_4$ emission in livestock [5].

This chapter will focus on four main areas: (i) livestock's role as a source of GHGs, and the contribution that this makes to climate change; (ii) enteric $CH_4$ emission and manure management related to $CH_4$ and $N_2O$ as primary sources of GHGs related to livestock activities; (iii) the methodologies used to quantify enteric emission; and (iv) modeling of GHGs in livestock farms as important step towards finding solution for livestock-related climate change.

## 2. Livestock and climate change from global food security perspectives

FAO estimated that 1526 million cattle and buffaloes and 1777 million small ruminants are being maintained globally. The population of cattle and buffaloes and small ruminants is expected to be 2.6 and 2.7 billion, respectively, by the year 2050. Furthermore, livestock are an integral element of agriculture that supports the livelihood of more than 1 billion people across the globe. This sector satisfies more than 13% of the caloric and 28% of the protein requirements of people worldwide. The global demand for milk, meat, and eggs is expected to increase by 30%, 60%, and 80%, respectively, by the year 2050 in comparison to the 1990 demand. This increased requirement will be fulfilled either by increasing the livestock numbers or through intensifying the productivity of existing stock.

Climate change is seen as a major threat to the survival of many species, ecosystems, and the sustainability of livestock production systems in many parts of the world [6]. The growing human population will almost doubled the global requirement for livestock products by 2050. It is during the same period adverse changes in the climate are also expected. Recent industrial developments have curtailed the land used for agricultural activities, considerably threatening food security in both developed and developing countries. Hence, livestock production has a key role to play in bringing food security to these countries. We need high-quality research in animal science to meet the increasing demand for livestock products in the changing climate scenario [7].

## 3. Livestock as source of greenhouse gas (GHGs)

Livestock contributes both directly and indirectly to climate change through the emissions of GHGs such as $CO_2$, $CH_4$, and $N_2O$ [8]. Globally, the sector contributes 18% (7.1 billion tonnes $CO_2$ equivalent) of global GHG emissions. Although it accounts for only 9% of global $CO_2$, it generates 65% of human-related $N_2O$ and 35% of $CH_4$, which has 310 times and 23 times the global warming potential (GWP) of $CO_2$, respectively [9] (Fig. 1).

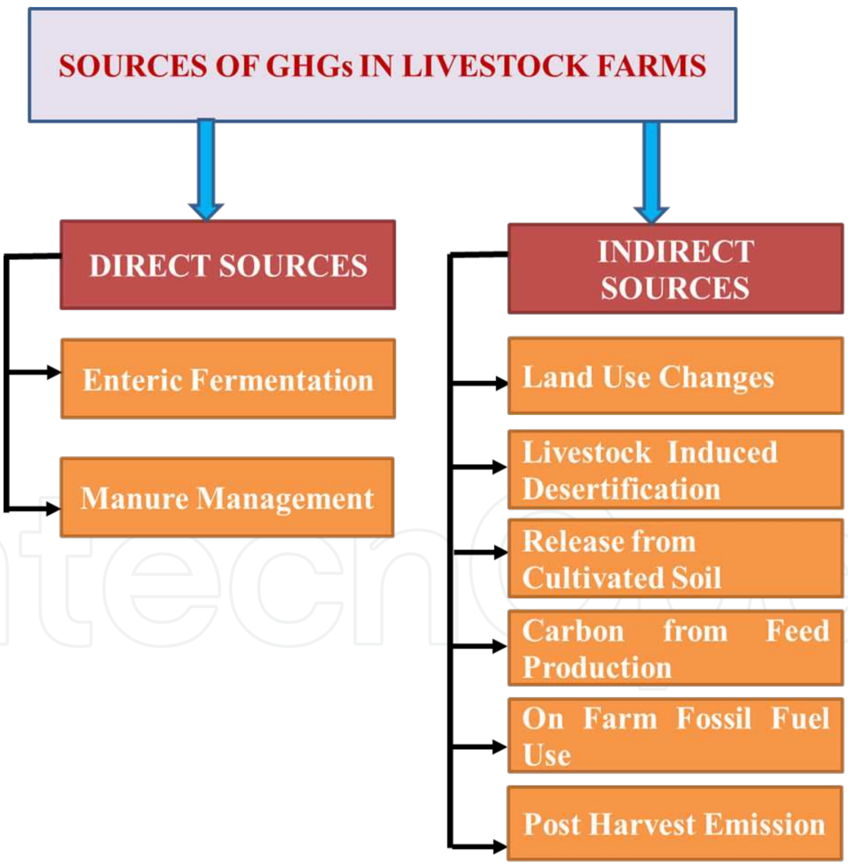


**Figure 1.** Different sources of GHGs from livestock sector.

There are two sources of GHG emissions from livestock: (a) enteric fermentation where specific microbes residing in the rumen produce $CH_4$ as a by-product during digestion and (b) anaerobic fermentation of livestock manure producing $CH_4$ and denitrification and denitrification of manure producing $N_2O$. Methane production appears to be a major issue and largely arises from natural anaerobic ecosystems, and fermentative digestion in ruminant animal [10]. Much of the global GHG emissions currently arise from enteric fermentation and manure from grazing animals. The development of management strategies to mitigate $CH_4$ emissions from ruminant livestock is possible and desirable. Carbon dioxide ($CO_2$) are also produced in livestock farms and are primarily associated with fossil fuel burning during operation of farm machineries in the process of fertilizer production, processing and transportation of refrigerated products, deforestation, desertification, and release of carbon from cultivated soils. Enhanced utilization of dietary "C" will improve energy utilization and feed efficiency hence animal productivity, decrease overall $CH_4$ emissions, and thereby reduce the contribution of ruminant livestock to the global $CH_4$ inventory.

Ruminant animals, such as cattle, sheep, buffaloes, and goats, are unique due to their special digestive systems, which can convert plant materials that are indigestible by humans into nutritious food. In addition to food, these animals also produce hides and fibers that are utilized by humans. This same helpful digestive system, however, produces $CH_4$, a potent GHG that can contribute to global climate change. Livestock production systems can also emit other GHGs such as $N_2O$ and $CO_2$. The most important GHGs are $CO_2$, $CH_4$, and $N_2O$, all of which have increased in the last 150 years and have different global warming potential. According to Sejian et al. [11], the warming potential of $CO_2$, $CH_4$, and $N_2O$ are 1, 25, and 310, respectively. Taking into account the entire livestock commodity chain – from land use and feed production, to livestock farming and waste management, to product processing and transportation – about 18% of total anthropogenic GHG emissions can be attributed to the livestock sector [2].

Livestock production is the largest global source of $CH_4$ and $N_2O$ – two particularly potent GHGs [12, 13]. The principal sources of $N_2O$ are manure and fertilizers used in the production of feed. The biggest source of $CH_4$ is from enteric fermentation. The rising demand for livestock products therefore translates into rising emissions of $CH_4$ and $N_2O$. According to one study, if current dietary trends (increasing global consumption of animal products) were to continue, emissions of $CH_4$ and $N_2O$ would more than double by 2055 from 1995 levels [14].

### 3.1. Enteric methane emission

Worldwide livestock emits around 7.1 Gt $CO_2$-eq GHGs per year, which accounts for 15% of the human induced GHGs emissions. Additionally, 5.7 Gt $CO_2$-eq GHGs is also emitted from the ruminant supply chain wherein cattle, buffaloes, and small ruminant production contribute 81%, 11%, and 8%, respectively. Methane emissions from livestock have two sources, one from enteric fermentation and another from excrement. Enteric fermentation in ruminants annually contributes ~90 Tg $CH_4$ to the atmospheric pool, while ~25 Tg comes from the excrement. Apart from the role of enteric $CH_4$ in global warming, its emission from the animal system lead to a loss of biological energy (6–12% of intake), which otherwise would have been utilized by the host animal for various productive functions. Reducing the loss of energy in the form of enteric $CH_4$ is crucial, especially in developing countries like India where feed and fodder availability is already in short supply.

### *3.1.1. Indian livestock and enteric methane emission*

India has approximately 512 million livestock (19th Livestock census, Government of India). Of the total livestock population, about 60% are cattle and buffaloes, which comparatively emit more enteric $CH_4$ than any other livestock species. Emissions of enteric $CH_4$ can be elevated when these species are fed fibrous feeds. Estimations of enteric $CH_4$ emissions from Indian livestock have been calculated using different approaches (Table 1). There is a lack of consistency in the published data; some have reported very high emissions from Indian livestock while others have reported much lower emissions [15]. This large variation in predicted enteric $CH_4$ emission from Indian livestock is attributed to the different approaches used for the calculation of emissions. The average of the published data is in the range of 9–10 Tg per year, which appears to be a realistic value. Methane emissions from excrement in India are low because the disposal system (generally stored as heap in the open environment) does not support the favorable anaerobic conditions required by methanogens. However, in the developed world where excrement is mainly stored in lagoons, manure is a major source of $CH_4$ emissions.

| Source | Base year | Emission (Tg/yr) | Approach |
|---|---|---|---|
| Ahuja [16] | 1985 | 10.40 | Default $CH_4$ emission factors |
| ALGAS[a] [17] | 1990 | 18.48 | IPCC methodology |
| Singh [18] | 1992 | 9.02 | *In vitro* gas production and dry matter digestibility coefficients |
| Garg and Shukla [15] | - | 7.25 | - |
| EPA[b] [19] | - | 10.04 | - |
| Swamy and Bhattacharya [20] | 1994 | 9.0 | Methane emission factors |
| Jha et al. [21] | 1994 | 8.97 | IPCC tier II |
| Chhabra et al. [22] | 2003 | 10.65 | GIS approach |
| Singh et al. [23] | 2003 | 9.10 | *In vitro* gas production, feeding practices in different agro-ecological regions |
| Patra [24] | 2010 | 14.3 | IPCC tier 1 |

[a]Asia Least-Cost Greenhouse Gas Abatement Strategy.

[b]United States Environmental Protection Agency.

**Table 1.** Estimates of enteric methane emission from Indian livestock

Based on the IPCC default emission factors, Kamra [25] determined the enteric $CH_4$ emission from Indian livestock. Buffalo, yak, and mithun contribute a maximum of 55 kg $CH_4$/head/yr; however, sheep and goat contribute only 5 kg/head/yr. The enteric $CH_4$ emission from crossbred cattle is much higher than the indigenous cattle (46 vs 25 kg/head/yr). Both cattle and buffaloes aggregately emit more than 90% of the total enteric $CH_4$ from livestock, while sheep and goat together contribute around 7.70% (Fig. 2). Pig production is the next major emitter contributing 0.57% of the total enteric $CH_4$ emission from livestock in India. The contribution from other livestock species is negligible.

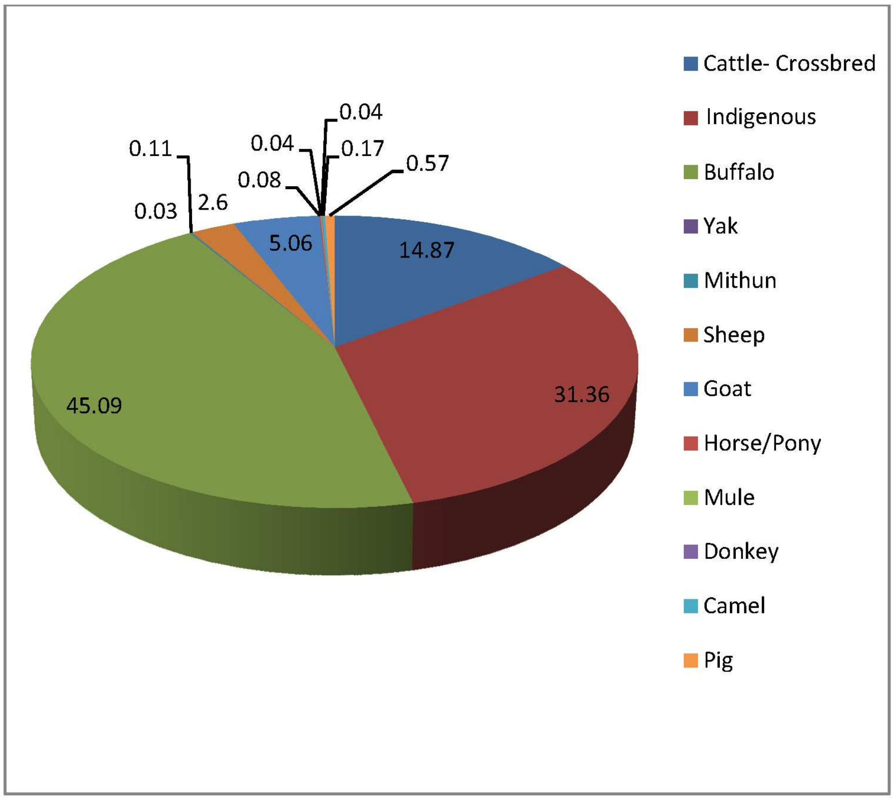


**Figure 2.** % Species wise enteric methane emission (modified from Kamra [25]).

### *3.1.2. Why rumen methanogenesis is an obligation*

The rumen is the harbor for diverse anaerobic microbe populations that accomplish different functions from degradation of complex carbohydrates to the removal of fermentation metabolites in a syntrophic way [26]. $H_2$, which is produced in large volumes during enteric fermentation, needs to be removed from the anaerobic vat in order to maintain favorable rumen conditions for both the rumen microbes and host animal. Under normal rumen functioning, metabolic $H_2$ is used for the reduction of $CO_2$ to $CH_4$, which in turn is eructated into the atmosphere via the mouth and nostrils. The microbes of the so-called *archaea* or methanogens are the $CH_4$ producing machinery inside the rumen. The majority of the rumen methanogens are hydrogenotrophic, which utilize $H_2$ as a substrate for methanogenesis.

http://dx.doi.org/10.5772/62135

Rumen methanogenesis is a necessary but energy-wasteful process as it corresponds to a significant loss of biological dietary energy (6–12% of intake) in the form of $CH_4$.

Among the various end products of rumen fermentation, $H_2$ is a central metabolite where its partial pressure in the rumen determines the extent of methanogenesis and the possible extent of oxidation of feedstuffs [27]. $H_2$ in the rumen is generally referred as *currency of fermentation* [27]. The removal of $H_2$ from the rumen is a prerequisite for the continuation of rumen fermentation. However, the methanogens constitute only a small fraction of the rumen microbial community, but they are very crucial in $H_2$ utilization [28]. Apart from the methanogenesis, other hydrogenotrophic pathways (reductive acetogenesis, sulfate and nitrate reduction) are also present in the rumen, but the extent of $H_2$ utilization through these pathways is not clear. In order to keep the rumen functional and the animal alive, rumen methanogenesis is the primary and thermodynamically efficient way of metabolic $H_2$ disposal from the rumen, and that is why it is generally regarded as a necessary but wasteful process.

#### *3.1.3. Enteric methane estimation methodology*

Several methods are available for measuring enteric $CH_4$ production, and the selection of the most appropriate method is based on several factors such as cost, level of accuracy, and experimental design [29, 30].

##### *3.1.3.1. Individual animal techniques*

By far, the most suitable method to quantify individual ruminant animal $CH_4$ measurement is by using respiration chamber, or calorimetry. The respiration chamber models include whole animal chambers, head boxes, or ventilated hoods and face masks. These methods have been effectively used to collect information pertaining to $CH_4$ emissions in livestock. The predominant use of calorimeters has been in energy balance experiments where $CH_4$ has been estimated as a part of the procedures followed. Although there are various designs available, open-circuit calorimeter has been the one widely used. There are various designs of calorimeters, but the most common one is the open-circuit calorimeter, in which outside air is circulated around the animal's head, mouth, and nose and expired air is collected for further analysis.

##### *3.1.3.2. Tracer gas techniques*

Methane emission from ruminants can be estimated by using the ERUCT technique (Emissions from Ruminants Using a Calibrated Tracer). The tracer can either be isotopic or nonisotopic. Isotopic tracer techniques generally require simple experimental designs and relatively straightforward calculations [31]. Isotopic methods involve the use of (3H-)$CH_4$ or (14C-)$CH_4$ and ruminally cannulated animals.

##### *3.1.3.3. Sulphur hexafluoride ($SF_6$) technique*

Nonisotopic tracer techniques are also available for measurement of $CH_4$ production. Johnson et al. [32] described a technique using $SF_6$, an inert gas tracer. This method has been widely used in sheep and cattle. Methane emission rates are calculated based on the equation $QCH_4 = QSF_6 \times [CH_4] / [SF_6]$, where $QCH_4$ is the emission rate of $CH_4$ in g/day, $QSF_6$ is the known release rate (g/day) of $SF_6$ from the permeation tube, and $[CH_4]$ and $[SF_6]$ are the measured concentrations in the canister.

#### *3.1.3.4. In vitro gas production technique (IVGPT)*

Various aspects of in vitro gas production test have been reviewed by Getachew et al. [33], and these authors reported that gas measurement were centered on investigations of rumen microbial activities using manometric measurements and concluded that these methods do not have wide acceptability in routine feed evaluation since there was no provision for the mechanical stirring of the sample during incubation. Another *in vitro* automated pressure transducer method for gas production measurement was developed by Wilkins [34], and the method was validated by Blummel and Orskov [35] and Makkar et al. [36]. There are several other gas-measuring techniques such as (i) Hohenheim gas method or Menke's method [37]; (ii) liquid displacement system [38]; (iii) manometric method [39]; (iv) pressure transducer systems: manual [40], computerized [41], and combination of pressure transducer and gas release system [42].

### 3.2. Livestock manure as an important source of GHGs

In addition to enteric $CH_4$ production, livestock manure contributes directly and indirectly to GHG gas production via $CH_4$, $N_2O$, and $CO_2$ production. Manure from livestock includes both dung and urine. Manure management plays a key role in amount of $CH_4$ and $N_2O$ produced and liberated into the environment. The amount of $CH_4$ produced in solid-state manure management contribute less when compared to liquid state. However, dry anaerobic management system provides suitable environment for $N_2O$ production. The liquid/slurry manure systems provide favorable environments for the growth of the microbes, which in turn enhances the $CH_4$ gas production. Various factors that affect $CH_4$ and $N_2O$ production include the amount of manure, the VFA present, the type of feed, the management systems, and the ambient temperature. In addition, the duration of the storage of waste also influences $N_2O$ production,

#### *3.2.1. Methane emission from manure management*

Anaerobic digestion processes occur in manure with the help of microbial consortia to produce $CH_4$ and $CO_2$ and consists of four phases: (i) hydrolysis of complex organic particulate matter into simpler low molecular weight compounds; (ii) acidogenesis of simpler low molecular weight organic compounds to organic acids and alcohol; (iii) acetogenesis of organic acids and alcohols to $H_2$, $CO_2$, acetic acid, and acetate; and (iv) methanogenesis involves the consumption of acids or hydrogen to produce $CH_4$ and $CO_2$. The aforementioned four phases are done by four different groups of bacterial consortia, namely, hydrolytic bacteria, acidogenic bacteria, acetogenic bacteria, and methanogenic bacteria, respectively [43]. $CH_4$ is also emitted from the collection yard, but it is a minor source. The greatest amount of $CH_4$ is emitted during storage especially in slurry, the reason being the prevalence of complete anaerobic environment. Solid manure also acts as a source of $CH_4$ emission. $CH_4$ is emitted immediately after manure application to the field; however, once the $O_2$ diffuses into manure, it inhibits $CH_4$ production [44].

*3.2.1.1. Factors affecting methane production from manure*

There are several factors that affect the $CH_4$ production from manure, which includes temperature, organic matter present, microbe load, pH, moisture, and type of feed. However, $CH_4$ emitted from manure depends primarily on (i) the management system such as solid disposal system, liquid disposal systems, e.g., ponds, lagoons, and tanks, which can emit up to 80% of manure-based $CH_4$ emissions, while solid manure emits little or no $CH_4$. (ii) Environmental conditions are also important. The higher the temperature and moisture, the more $CH_4$ produced. (iii) $CH_4$ emissions also depend on the quantity of the manure produced, which depends on the number of animals housed, the amount of feed the consumed, and the digestibility of the feed. (iv) Manure characteristics depend on the animal type, feed quality, and rumen microbes present in the rumen and digestive tracks. Manure handled in liquid form tends to release more amount of $CH_4$ when compared to solid or manures thrown into the pasture, which do not decompose anaerobically. High temperatures with neutral pH and high moisture content enhance $CH_4$ production [45].

*3.2.2. Nitrous oxide emission from manure management*

Nitrous oxide is produced from manure by nitrification, denitrification, leaching, volatilization, and runoff. Nitrification and denitrification are direct emissions. $N_2O$ is 16 times more potent than $CH_4$ and 310 times more potent than $CO_2$ over a 100-year period [46]. $N_2O$ acts as a source of NO in the stratosphere, which indirectly causes depletion of ozone ($O_3$), increasing UV radiation reaching the Earth's surface [47]. An increase in animal stocking rates and intensive gazing results in the deposition of huge amounts of N via animal excreta (urine + dung); farm management practices that enhance soil organic N mineralization also lead to $N_2O$ production [1, 48, 49].

*3.2.2.1. Mechanism of nitrous oxide production*

The emission of $N_2O$ from manure occurs directly by both nitrification and denitrification of nitrogen contained in the manure. This emission mainly depends on the N and C content of the manure during various types storage and treatment. The nitrification process strictly needs oxygen, while subsequent denitrification is an anaerobic process.

Manure from livestock mixes with the soil or in the tank, lagoons, etc., where the microbes break down organic N to inorganic $NH_4$+ through mineralization. In this step, the organic N becomes available for plants and microorganisms. Microorganisms (*Nitrosomonas* genus) can take up $NH_4$+ and oxidize it to nitrite ($NO_2$-). In the next step, *Nitrobacter* and *Nitrococcus* oxidize $NO_2$- to nitrate ($NO_3$-) by nitrification. This process of oxidation of $NH_4$+ to $NO_3$- is known as nitrification, which is also done by other genera like *Nitrosococus and Nitrosospira* and subgenera *Nitrosobolus* and *Nitrosovibrio* [50, 51].

Studies show that $N_2O$ was emitted from animal houses at the rate of 4–5 mg N $m^{-2}$ $d^{-1}$, with straw as bedding material, whereas when no bedding material was used, little or no $N_2O$ was emitted from slurry-based cattle or pig building as complete anaerobic condition would have maintained [52]. Deep litter system with fattening pigs showed much higher emission compared to slurry based pig houses, while mechanical mixing still further increased $N_2O$ emission [53]. In cattle collection yards, there had been very less or no $N_2O$ emission as the anaerobic condition prevents conversion of $NH_4$+ to $NO_3$-.

Stored solid manures acts as a source of $N_2O$ production/consumption and emission. Covering heaped manure shows reduction in $NH_3$ emissions but has no effect on $N_2O$ emission, while other studies showed that both were reduced. The addition of chopped straw reduced $N_2O$ emission by 32% from the small scale of cattle manure. [54]. Slurry or liquid manure with no cover showed negligible $N_2O$ release, while slurry with straw cover might act as a source of emission [55]. $N_2O$ emission occurs following manure application to soil [56]. Various factors that affect $N_2O$ release from soil include (i) type of manure, (ii) soil type, (iii) manure composition, (iv) measurement period, (v) timing of manure application, (vi) amount of manure applied, and (vii) method of application.

### 3.3. Other sources of GHGs from livestock farm

If all parts of the livestock production lifecycle are included, livestock are estimated to account for 18% of global anthropogenic emissions [57]. According to Gill and coworkers [57], apart from enteric fermentation and manure management, the other sources of GHG emission from livestock and related activities are fossil fuels used during feed and fertilizer production and transport of processed animal products.

## 4. Models for forecasting the greenhouse gas emission in livestock farms

Agricultural production is recognized as a significant contributor to GHG production. Intensive dairy production, in particular, contributes to significant quantities of $CH_4$ and several forms of nitrogen (N), which can contribute to $N_2O$ production. Over the past 10 years, research studies have attempted to address various sources of GHG emissions within the dairy production system. These sources have included housing [58], manure removal, storage, and treatment systems [59]. Others have compared GHG emissions from conventional farming practices to those employed in organic production. Many of these studies have looked at one section of the production chain in isolation. However, dairy production is a complex system involving inputs such as feed and fertilizer, animals with inherent physiological structures for fermentation of feedstuffs, and the production of manure, storage systems, cropping systems, and export of meat and milk.

It is very easy to understand that attempting to design and conduct research trials to ascertain the effect of one or multiple changes on production, economics, and GHG emissions from a dairy production system would be expensive and time consuming. Therefore, the use of whole farm models, with short-term studies for validation, is an attractive alternative. The integrated

http://dx.doi.org/10.5772/62135

farm system model (IFSM) apart from evaluating alternate agronomic feeding, manure storage, and disposal strategies, also accounts for fossil fuel used in farming activities. In real sense, these models do not predict production of GHG but assist in generating some basic information required to predict GHG based on published data.

The development of whole-farm approaches for the mitigation of GHG emissions has been taken up recently by several research groups. A common feature of whole farm models is the ability to calculate $CH_4$ and $N_2O$ emissions from all farm activities. Furthermore, the models vary considerably on many other aspects. General characteristics of whole farm models include model type, $CH_4$ and $N_2O$ emissions, $CO_2$ emissions, C sequestration, $NH_3$ and $NO_3$ emissions, P cycling, pre chain emissions, animal welfare, economics, biodiversity, product quality, soil quality, and landscape aesthetics [60]. Whole farm model (WFM) uses pasture growth and cow metabolism for predicting $CH_4$ emissions in dairy farms. Also included in the WFM is climate and management information. However, recent reports also suggests that WFMs may incorrectly estimate $CH_4$ emission levels as they do not take into account the DMI and diet composition while predicting the enteric $CH_4$ emission. This low prediction efficiency of WFMs may lead to substantial error in GHG inventories [10, 11].

The integrated farm system model (IFSM) is a simulation model that integrates the major biological and physical processes of a crop, beef, or dairy farm and evaluating the overall impact of management strategies used to reduce $CH_4$ emissions [61, 62]. The IFSM is a process-based whole farm simulation including major components for soil processes, crop growth, tillage, planting and harvest operations, feed storage, feeding, herd production, manure storage, and economics [63]. IFSM predicts the effect of management scenarios on farm performance, profitability, and environmental pollutants such as nitrate leaching, ammonia volatilization, and phosphorus runoff loss. The dairy greenhouse gas model (DairyGHG) is a type of IFSM that was developed to provide an easy to use software tool for estimating GHG emissions and the carbon footprint of dairy production systems [64]. Recently, FAO developed a global livestock environmental assessment model (GLEAM), which reported that livestock-related activities contributed around 7.1 gigatonnes $CO_2$-eq per annum, indicating the prominent contribution of livestock to climate change [65].

A whole-farm approach is a powerful tool for the development of cost-effective GHG mitigation option. The modeling technology can be used to assess the technical, environmental, and financial implications of alternative farm management strategies, under changing external conditions. Whole farm models (WFMs) can reveal relevant interactions between farm components and is useful for integrated scenario development and evaluation. Further, the whole-farm approach ensures that the potential negative trade-offs are taken into account and that positive synergies are identified. In addition, the whole farm models are also used to explore future farm strategies, and since it is operated on farming level, it also provides opportunity for farmers to learn and understand the underlying processes on their own farm. Hence, the whole-farm approach is also helpful in communicating the mitigation option to the farmers, and this could be more beneficial if the models additionally evaluate costs and benefits associating with farming activities.

## 5. Conclusion

Livestock undoubtedly need to be a priority focus of attention as the global community seeks to address the challenge of climate change. Livestock contribute directly as well as indirectly to global GHG pool. The two primary sources of GHG from livestock are enteric fermentation and manure management. There are several techniques available to quantify $CH_4$ emission, and the application of appropriate technique depends on objectives of the study. Further, simulation models offer a great scope to predict accurately the GHG emission in farm as a whole. This information will be very valuable in understanding the role of livestock to climate change in depth, and this understanding will help in designing suitable mitigation strategies to reduce livestock-related GHGs.

## Author details

Veerasamy Sejian[1,2*], Raghavendra Bhatta[1], Pradeep Kumar Malik[1], Bagath Madiajagan[1], Yaqoub Ali Saif Al-Hosni[2], Megan Sullivan[2] and John B. Gaughan[2]

*Address all correspondence to: drsejian@gmail.com

1 ICAR-National Institute of Animal Nutrition and Physiology, Adugodi, Bangalore, Karnataka, India

2 School of Agriculture and Food Sciences (Animal Science) The University of Queensland, Gatton, QLD, Australia

## References

[1] Intergovernmental Panel on Climate Change (IPCC). Climate Change: Synthesis Report; Summary for Policymakers. Retrieved from: http://www.ipcc. ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf. 2007.

[2] Food and Agriculture Organization of the United Nations (FAO). Livestock a Major Threat to the Environment: Remedies Urgently Needed. Retrieved from: http://www.fao.org/newsroom/en/news/2006/ 1000448/index.html. 2006.

[3] Gleik PH, Adams RM, Amasino RM. Climate change and the integrity of science. Science. 2010; 328: 689–691.

[4] Sejian V, Gaughan J, Baumgard L, Prasad CS. Climate Change Impact on Livestock: Adaptation and Mitigation. Springer-Verlag GMbH Publisher, New Delhi, India, 2015a; pp. 1–532.

http://dx.doi.org/10.5772/62135

[5] Malik PK, Bhatta R, Takahashi J, Kohn RA, Prasad CS. Livestock production and climate change. CABI Climate Change Series 6, CABI Nosworthy Way, Wallingford, UK. 2015a, pp. 1–408.

[6] Moss AR, Jounany JP, Neevbold J. Methane production by ruminants: its contribution to global warming. Ann. Zootech. 2000; 49: 231–253.

[7] Naqvi SMK, Sejian V. Global climate change: role of livestock. Asian Journal of Agricultural Sciences. 2011; 3(1): 19–25.

[8] Bhatta R, Malik PK, Prasad CS. Enteric methane emission: status, mitigation and future challenges—an Indian perspective (chapter 15). In: Malik PK, Bhatta R, Takahashi J, Kohn RA, and Prasad CS (eds.), *Livestock Production and Climate Change*. Publisher CABI, Oxfordshire, UK & CABI, Boston, MA, USA. 2015; pp. 229–244.

[9] Food and Agriculture Organization of the United Nations (FAO). Submission to UNFCCC AWG LCA, Enabling Agriculture to Contribute to Climate Change. Retrieved from: http://unfccc.int/resource/ docs/2008/smsn/igo/036.pdf. 2009.

[10] Sejian V, Indu S, Ujor V, Ezeji T, Lakritz J, Lal R. Global climate change: enteric methane reduction strategies in livestock. In: Environmental stress and amelioration in livestock production. Sejian V, Naqvi SMK, Ezeji T, Lakritz J, and Lal R (eds.), Springer-Verlag GMbH Publisher, Germany. 2012; pp. 469–502.

[11] Sejian V, Lal R, Lakritz J, Ezeji T. Measurement and Prediction of Enteric Methane Emission. International Journal of Biometeorology. 2011a; 55: 1–16.

[12] Food and Agriculture Organization of the United Nations (FAO). Tackling Climate through Livestock: A Global Assessment of Emissions and Mitigation Opportunities, Rome: FAO. 2013.

[13] Intergovernmental Panel on Climate Change (IPCC). Climate Change 2014: Mitigation of Climate Change, Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Edenhofer O, Pichs-Madruga R, Sokona Y, Farahani E, Kadner S, Seyboth K, Adler A, Baum A, Brunner A, Eickemeier P, Kriemann B, Savolainen J, Schlömer S, von Stechow C, Zwickel T, and Minx JC (eds.), Cambridge University Press, Cambridge. 2014.

[14] Popp A, Lotze-Campen H, Bodirsky B. Food consumption, diet shifts and associated non-$CO_2$ greenhouse gases from agricultural production. Global Environmental Change. 2010; 20: 451–62.

[15] Garg A, Shukla PR. Emission Inventory of India. Tata McGraw Hill Publishing Co Ltd., New Delhi. 2002. p. 84.

[16] Ahuja D. Climate Change. Technical series U S, UPA Report, 1990.

[17] ALGAS. Asia least-cost greenhouse gas abatement strategy: India, ADB–GEF–UNDP, Asian Development Bank and United Nations Development Programme, Manila, the Philippines, 1998, pp. 238.

[18] Singh GP. Methanogenesis and production of greenhouse gases under animal husbandry system. Report of AP Cess Fund Project, National Dairy Research Institute, Karnal, India. 1998.

[19] Environmental Protection Agency (EPA). Inventory of U S greenhouse gas emissions and sinks: 1990–2000, U S Environmental Protection Agency, EPA 430–R–02–003. 1994.

[20] Swamy M, Bhattacharya, S. Budgeting anthropogenic greenhouse gas emission from Indian livestock using country specific emission coefficients. Current Science. 2006; 91:1340–53.

[21] Jha AK, Singh K, Sharma C, Singh SK, Gupta PK. Assessment of methane and nitrous oxide emissions from livestock in India. Earth Science and Climatic Change. doi.org/10.4172/2157-7617.1000107. 2011.

[22] Chhabra A, Manjunath KR, Panigrahy S, Parihar JS. Spatial pattern of methane emission from Indian livestock. Current Science. 2009; 96: 683–89.

[23] Singh S, Kushwaha BP, Nag SK, Bhattacharya S, Gupta PK Mishra AK, Singh A. Assessment of enteric methane emission of Indian livestock in different agro-ecological regions. Current Science. 2012; 102: 1017–1027.

[24] Patra AK. Trends and projected estimates of GHG emissions from Indian livestock in comparisons with GHG emissions from world and developing countries. Asian-Australasian Journal of Animal Science. 2014. 27: 592–599.

[25] Kamra DN. Enteric methane mitigation: present status and future Prospects. In: Proceedings of Global Animal Nutrition Conference (2014) held at Bangalore, 20–22 April, 2014. pp. 77–87.

[26] Malik PK, Bhatta R, Soren NM, Sejian V, Mech A, Prasad KS, Prasad CS. Feed-based approaches in enteric methane amelioration. In: Malik PK, Bhatta R, Takahashi J, Kohn RA, and Prasad CS (eds.), Livestock production and climate change. CABI Climate Change Series 6, CABI Nosworthy Way, Wallingford, UK. 2015b; pp. 336–359.

[27] Hegarty RS, Gerdes R. Hydrogen production and transfer in the rumen. Recent Advances in Animal Nutrition in Australia, 1999; p. 12.

[28] anssen PH, Kirs M. Structure of the archaeal community of the rumen. Applied Environmental Microbiology. 2008; 74: 3619–3625.

[29] Bhatta R, Enishi O, Kurihara M. Measurement of methane production from ruminants-a review. Asian Australasian Journal of Animal Sciences. 2006a; 20: 1305–1318.

[30] Bhatta R, Tajima K, Kurihara M. Influence of temperature and pH on fermentation pattern and methane production in the rumen simulating fermenter (RUSITEC). Asian Australasian Journal of Animal Sciences. 2006b; 19 (3): 376–380.

[31] Johnson KA, Johnson DE. Methane emissions from cattle. Journal of Animal Science. 1995; 73: 2483–2492.

[32] Johnson KA, Westberg HH, Lamb BK, Kincaid RL. The use of sulphur hexafluoride for measuring methane emissions from farm animals. In Proceedings of the 1st International Conference on Greenhouse Gases and Animal Agriculture, Obihiro, Hokkaido, Japan. 2001. pp. 72–81.

[33] Getachew G, Blummel M, Makkar HPS, Becker K. In vitro gas measuring techniques for assessment of nutritional quality of feeds: a review. Animal Feed Science and Technology. 1998; 72: 261–281.

[34] Wilkins JR. Pressure transducer method for measuring gas production by micro organisms. Applied Microbiology. 1974; 27: 135–140.

[35] Blummel M, Orskov ER. Comparison of gas production and nylon bag degradability of roughages in predicting feed intake in cattle. Animal Feed Science and Technology. 1993; 40:109–119.

[36] Makkar HPS, Blummel M, Becker K. Formation of complexes between polyvinyl pyrrolidones or polyethylene glycols and tannins, and their implication in gas production and true digestibility in *in vitro* techniques. British Journal of Nutrition.1995; 73: 897–913.

[37] Menke KH, Raab L, Salewski A, Steingass H, Fritz D, Schneider W. The estimation of the digestibility and metabolizable energy content of ruminant feeding stuffs from the gas production when they are incubated with rumen liquor. Journal of Agricultural Science. 1979; 93: 217–222.

[38] Beuvink JMW, Spoelstra SF, Hogendorp RJ. An automated method for measuring time-course of gas production of feedstuff incubated with buffered rumen fluid. Netherland Journal of Agricultural Science. 1992; 40: 401–407.

[39] Waghorn GC, Stafford KJ. Gas production and nitrogen digestion by rumen microbes from deer and sheep. New Zealand Journal Agricultural Research. 1993; 36: 493–497.

[40] Theodorou MK, Williams BA, Dhanoa MS, McAllan AB, France J. A simple gas production method using a pressure transducer to determine the fermentation kinetics of ruminant feeds. Animal Feed Science and Technology 1994; 48: 185–197.

[41] Pell AN, Schofield P. Computerised monitoring of gas production to measure forage digestion. Journal of Dairy Science. 1993. 76: 1063–1073.

[42] Cone JW, Gelder AH, Visscher GJW, Oudshoorn L. Influence of rumen fluid and substrate concentration on fermentation kinetics measured with fully automated time related gas production apparatus. Animal Feed Science and Technology. 1996; 61: 113–128.

[43] Schnürer A, Jarvis A. Microbial Handbook for Biogas Plants, Swedish Waste Management U2009: 2010; 03.

[44] Chadwick D, Sommer S, Thorman R, Fangueiro D, Cardenas L, Amon B, Brook TM. Manure management: implications for greenhouse gas emissions. Animal Feed Science and Technology. 2011; 166:514–531.

[45] Bull P, McMillan C, Yamamoto A. Michigan Greenhouse Gas Inventory 1990 and 2002; Report No. CSS05–07. Centre for Sustainable Systems, University of Michigan: City, MI, USA. 2005.

[46] Intergovernmental Panel on Climate Change (IPCC). Greenhouse Gas Inventory Reporting Instructions. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories; UNEP, WMO, OECD and IEA: Bracknell, UK. 1997.

[47] Duxbury JM, Harper LA, Mosier AR. Contributions of agroecosystems to global climate change. Agricultural Ecosystem Effects on Trace Gases and Global Climate Change. American Society of Agronomy. 1993. pp. 1–18.

[48] Zaman M, Blennerhassett JD. Effects of the different rates of urease and nitrification inhibitors on gaseous emissions of ammonia and nitrous oxide, nitrate leaching and pasture production from urine patches in an intensive grazed pasture system. Agriculture Ecosystems and Environment. 2010; 136: 236–246.

[49] Zaman M, Nguyen ML. Effect of lime or zeolite on $N_2O$ and N emissions from a pastoral soil treated with urine or nitrate-N fertiliser under field conditions. Agriculture Ecosystems and Environment. 2010; 136: 254–261.

[50] Bremner JM, Blackmer AM. Terrestrial nitrification as a source of atmospheric nitrous oxide. In: Delwiche CC (ed.), Denitrification, Nitrification and Atmospheric Nitrous Oxide. Willey and Sons, New York, 1981. pp. 151–170.

[51] Watson SW, Valos FW, Waterbury JB. The family nitrobacteraceae. In: Starr MP, Stolp H, Trupe HG, Below AP, Shlegel HG (eds.), The Prokaryotes, A handbook on Habits, Isolation, and Identification of Bacteria. Springer-Verlag, Berlin. 1981.

[52] Thorman RE, Harrison R, Cooke SD, Chadwick DR, Burston M, Balsdon SL. Nitrous oxide emissions from slurry- and straw-based systems for cattle and pigs in relation to emissions of ammonia. In: McTaggart I and Gairns L (eds.), Proceedings of SAC/SEPA Conference on Agriculture, Waste and the Environment. Edinburgh (UK), 26–28 March 2002. pp. 26–32.

[53] Groenestein CM, Van Fassen HG. Volatilisation of ammonia, nitrous oxide and nitric oxide in deep-litter systems for fattening pigs. Journal of Agricultural Engineering and Research. 1996; 65: 269–274.

[54] Yamulki S. Effect of straw addition on nitrous oxide and methane emissions from stored farmyard manures. Agriculture Ecosystems and Environment. 2006; 112: 140–145.

[55] Sommer SG, Petersen SO, Sogaard HT. Greenhouse gas emission form stored livestock slurry. Journal of Environmental Quality. 2000; 29: 744–751.

[56] Sistani KR, Warren JG, Lovanh N, Higgins S, Shearer S. 2010. Greenhouse gas emissions from swine effluent applied to soil by different methods. Soil Science Society of America Journal. 74: 429–435.

[57] Gill M, Smith P, Wilkinson JM. Mitigating climate change: the role of domestic livestock. Animal. 2010; 4(3): 323–33.

[58] Ellis JL, Kebreab E, Odongo NE, McBride BW, Okine EK, France J. Prediction of methane production from dairy and beef cattle. Journal of Dairy Science. 2007; 90: 3456–3467.

[59] Amon B, Kryvoruchko V, Amon T, Zechmeister-Boltenstern S. Methane, nitrous oxide and ammonia emissions during storage and after application of dairy cattle slurry and influence of slurry treatment. Agriculture, Ecosystems and Environment. 2006; 112: 153–162.

[60] Sejian V, Hyder I, Ezeji T, Lakritz J, Bhatta R, Ravindra JP, Prasad CS, Lal R. Global warming: role of livestock. In: Sejian V, Gaughan J, Baumgard L, Prasad CS (eds.), Climate Change Impact on Livestock: Adaptation and Mitigation. Springer-Verlag GMbH Publisher, New Delhi, India, 2015b; p 141–170.

[61] Sejian V. Climate change, Green house gas emission and sheep production. In: Shinde AK, Swarnkar CP, and Prince LLL (eds.), Status Papers on Future Research in Sheep Production and Production Development, 50 Years Research Contributions(1962–2012), published by Director, Central Sheep and Wool Research Institute, Avikanagar, Rajasthan-304501, 2012; p. 155–178.

[62] Sejian V, Naqvi SMK. Livestock and climate change: mitigation strategies to reduce methane production. In: Guoxiang Liu (ed.), Greenhouse Gases—Capturing, Utilization and Reduction. Intech Publisher, Croatia, 2012; pp. 254–276.

[63] Rotz CA, Corson MS, Chianese DS, Coiner CU. The integrated farm system model: reference manual. University Park, PA: USDAARS Pasture Systems and Watershed Management research unit: www.ars.usda.gov/SP2UserFiles/Place/19020000/ifsmreference.2009.

[64] Sejian V, Rotz A, Lakritz J, Ezeji T, Lal R. Modeling of green house gas emissions in dairy farms. Journal of Animal Science Advances. 2011b; 1(1): 12–20.

[65] Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Falcucci A, Tempio G. Tackling climate change through livestock—a global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome. 2013.