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

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

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$_2$O). 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$_2$O emissions. Other sources of GHG emission from livestock and related activities are fossil fuels used for associated farm activities, N$_2$O 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

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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 1.8–3.9°C (3.2–7.1°F) by 2100. With business as usual, Earth’s temperature may rise by 1.4–5.8°C 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\(_2\)O) 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\(_2\)O 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$_2$O [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$_2$O and 35% of CH$_4$, which has 310 times and 23 times the global warming potential (GWP) of CO$_2$, respectively [9] (Fig. 1).

![Sources of GHGs in Livestock Farms](image)

**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$_2$O. 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$_2$O and CO$_2$. The most important GHGs are CO$_2$, CH$_4$, and N$_2$O, 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$_2$O 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$_2$O – two particularly potent GHGs [12, 13]. The principal sources of N$_2$O 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$_2$O. According to one study, if current dietary trends (increasing global consumption of animal products) were to continue, emissions of CH$_4$ and N$_2$O 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 \( \text{CH}_4 \) 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 \( \text{CH}_4 \) than any other livestock species. Emissions of enteric \( \text{CH}_4 \) can be elevated when these species are fed fibrous feeds. Estimations of enteric \( \text{CH}_4 \) 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 \( \text{CH}_4 \) 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 \( \text{CH}_4 \) emissions.

Source | Base year | Emission (Tg/yr) | Approach
--- | --- | --- | ---
Ahuja [16] | 1985 | 10.40 | Default \( \text{CH}_4 \) emission factors
ALGAS\(^a\) [17] | 1990 | 18.48 | IPCC methodology
Singh [18] | 1992 | 9.02 | In vitro gas production and dry matter digestibility coefficients
Singh et al. [23] | 2003 | 9.10 | In vitro gas production, feeding practices in different agro-ecological regions
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

\(^a\)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 CH₄ emission from Indian livestock. Buffalo, yak, and mithun contribute a maximum of 55 kg CH₄/head/yr; however, sheep and goat contribute only 5 kg/head/yr. The enteric CH₄ 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 CH₄ 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 CH₄ emission from livestock in India. The contribution from other livestock species is negligible.

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]. H₂, 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 H₂ is used for the reduction of CO₂ to CH₄, which in turn is eructated into the atmosphere via the mouth and nostrils. The microbes of the so-called *archaea* or methanogens are the CH₄ producing machinery inside the rumen. The majority of the rumen methanogens are hydrogenotrophic, which utilize H₂ as a substrate for methanogenesis.
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 CH₄.

Among the various end products of rumen fermentation, H₂ 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]. H₂ in the rumen is generally referred as currency of fermentation [27]. The removal of H₂ 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 H₂ 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 H₂ 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 H₂ 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 CH₄ 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 CH₄ 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 CH₄ emissions in livestock. The predominant use of calorimeters has been in energy balance experiments where CH₄ 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-)CH₄ or (14C-)CH₄ and ruminally cannulated animals.

3.1.3.3. Sulphur hexafluoride (SF₆) technique

Nonisotopic tracer techniques are also available for measurement of CH₄ production. Johnson et al. [32] described a technique using SF₆, an inert gas tracer. This method has been
widely used in sheep and cattle. Methane emission rates are calculated based on the equation \( Q_{CH_4} = Q_{SF_6} \times \frac{[CH_4]}{[SF_6]} \), where \( Q_{CH_4} \) is the emission rate of \( CH_4 \) in g/day, \( Q_{SF_6} \) 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 \( \text{CH}_4 \) emission. \( \text{CH}_4 \) is emitted immediately after manure application to the field; however, once the \( \text{O}_2 \) diffuses into manure, it inhibits \( \text{CH}_4 \) production [44].

3.2.1. Factors affecting methane production from manure

There are several factors that affect the \( \text{CH}_4 \) production from manure, which includes temperature, organic matter present, microbe load, \( \text{pH} \), moisture, and type of feed. However, \( \text{CH}_4 \) 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 \( \text{CH}_4 \) emissions, while solid manure emits little or no \( \text{CH}_4 \). (ii) Environmental conditions are also important. The higher the temperature and moisture, the more \( \text{CH}_4 \) produced. (iii) \( \text{CH}_4 \) 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 \( \text{CH}_4 \) when compared to solid or manures thrown into the pasture, which do not decompose anaerobically. High temperatures with neutral \( \text{pH} \) and high moisture content enhance \( \text{CH}_4 \) 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. \( \text{N}_2\text{O} \) is 16 times more potent than \( \text{CH}_4 \) and 310 times more potent than \( \text{CO}_2 \) over a 100-year period [46]. \( \text{N}_2\text{O} \) acts as a source of \( \text{NO} \) in the stratosphere, which indirectly causes depletion of ozone (\( \text{O}_3 \)), 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 \( \text{N} \) via animal excreta (urine + dung); farm management practices that enhance soil organic \( \text{N} \) mineralization also lead to \( \text{N}_2\text{O} \) production [1, 48, 49].

3.2.2.1. Mechanism of nitrous oxide production

The emission of \( \text{N}_2\text{O} \) from manure occurs directly by both nitrification and denitrification of nitrogen contained in the manure. This emission mainly depends on the \( \text{N} \) and \( \text{C} \) 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 \( \text{N} \) to inorganic \( \text{NH}_4^+ \) through mineralization. In this step, the organic \( \text{N} \) becomes available for plants and microorganisms. Microorganisms (\( \text{Nitrosomonas} \) genus) can take up \( \text{NH}_4^+ \) and oxidize it to nitrite (\( \text{NO}_2^- \)). In the next step, \( \text{Nitrobacter} \) and \( \text{Nitrococcus} \) oxidize \( \text{NO}_2^- \) to nitrate (\( \text{NO}_3^- \)) by nitrification. This process of oxidation of \( \text{NH}_4^+ \) to \( \text{NO}_3^- \) is known as nitrification, which is also done by other genera like \( \text{Nitrosococcus} \) and \( \text{Nitrosospira} \) and subgenera \( \text{Nitrosobolus} \) and \( \text{Nitrosativirio} \) [50, 51].
Studies show that \( \text{N}_2\text{O} \) 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 \( \text{N}_2\text{O} \) 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 \( \text{N}_2\text{O} \) emission [53]. In cattle collection yards, there had been very less or no \( \text{N}_2\text{O} \) emission as the anaerobic condition prevents conversion of \( \text{NH}_4^+ \) to \( \text{NO}_3^- \).

Stored solid manures acts as a source of \( \text{N}_2\text{O} \) production/consumption and emission. Covering heaped manure shows reduction in \( \text{NH}_3 \) emissions but has no effect on \( \text{N}_2\text{O} \) emission, while other studies showed that both were reduced. The addition of chopped straw reduced \( \text{N}_2\text{O} \) emission by 32% from the small scale of cattle manure. [54]. Slurry or liquid manure with no cover showed negligible \( \text{N}_2\text{O} \) release, while slurry with straw cover might act as a source of emission [55]. \( \text{N}_2\text{O} \) emission occurs following manure application to soil [56]. Various factors that affect \( \text{N}_2\text{O} \) 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 \( \text{CH}_4 \) and several forms of nitrogen (N), which can contribute to \( \text{N}_2\text{O} \) 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
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$_2$O 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$_2$O 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

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