__Review Article__

Green House Gas emissions and mitigation strategies for Sustainable Dairy Farming

Abstract:

The global dairy industry is estimated to be worth billions of dollars, with India being the leading producer of dairy products. Milk is a vital source of nutrition, providing energy, protein, and essential micronutrients. It has been linked to various health benefits, such as improved bone health and reduced risk of cardiovascular disease and type-2 diabetes. However, the livestock industry also contributes to greenhouse gas emissions, which contribute to climate change. The carbon footprint of dairy products is measured by assessing the emissions of greenhouse gases throughout the production process. Methane emissions from enteric fermentation and manure management are the primary sources of emissions in the livestock sector. Strategies aimed at enhanced milk production, reducing animal mortality rates and enhancing reproductive performances can also help reduce emissions. To ensure long-term sustainability of the livestock production system, the Indian dairy cattle farming system must address key intervention areas such as feeding management, animal health and reproductive performance, and manure management to reduce its carbon footprint.

Key words: dairy farming; carbon footprint; global warming; life cycle assessment

Introduction

The livestock production system is crucial for food security in both developed and developing nations [1]. Over 150 million farmers, accounting for over one-quarter of the total 570 million farm holdings globally, raise at least one milk animal, such as cows, buffaloes, goats, or sheep. The global milk production in 2019 amounted to 851.8 million tonnes, with an average per capita consumption of approximately 111.4 kg per year [2]. Livestock in developing economies play various roles, including providing household income, acting as a financial asset, ensuring food security, managing risks, and establishing a direct connection to human health [3-4]. The global dairy market is estimated to be worth around $893 billion in 2022, with an estimated value of $1243 billion in the future. The value of dairy exports from 2015 to 2022 was around $68 billion. India is the leading global producer of dairy products, accounting for a significant share of 24% of the world global production[5]. The livestock sector is important as a sub-sector within the Indian agricultural economy, contributing significantly to its overall economic development.

Livestock has significant potential for generating employment across various sectors, with dairy farming particularly crucial in several rural economies. The dairy sector substantially enhances household income and creates employment opportunities in rural regions, particularly for landless individuals, small-scale farmers, and female farmers [6]. Additionally, it serves as a source of affordable and nourishing food for a large population. Milk holds significant importance in human nutrition, providing ample energy and substantial quantities of protein and micronutrients such as calcium, magnesium, selenium, and vitamins like B_2, B_5, and B_{12}. It ranks as the fifth largest energy provider and the third largest supplier of protein and fat for human consumption. The nutritional benefits of dairy products, better bone health and the prevention of osteoporosis and other bone diseases, are widely acknowledged [7, 4].

The consumption of dairy products has been found to have a negative correlation with the occurrence of cardiovascular disease, with the intake of milk and other dairy products linked to a reduced risk of developing type-2 diabetes and enhanced glucose regulation [8]. There is evidence suggesting that consuming dairy products is linked to a reduced risk of developing certain types of cancer, such as colorectal, bladder, gastric, and breast cancer [9]. Recently, there has been a growing consumer apprehension regarding the ecological ramifications of food production. Environmental efficiency assessment in milk production worldwide often involves the examination of greenhouse gas (GHG) emissions resulting from dairy production [10]. The dairy industry must contribute to the global endeavor of mitigating the adverse impacts of climate change, enhancing its resilience, and adapting to evolving climatic conditions. To mitigate the increase in temperature, the dairy industry must decrease its emissions of greenhouse gases and strive towards a future with reduced carbon intensity. This review aims to comprehensively analyze the dairy industry's role in global greenhouse gas emissions, focusing on mitigating the challenges posed by climate change and formulating a sustainable approach for the sector to reduce its carbon footprint.

Carbon footprint and dairy industry

The carbon footprint is the comprehensive measure of greenhouse gas (GHG) emissions attributed to the production of a product, such as milk. The commonly used metric for quantifying greenhouse gas emissions is often expressed as the carbon dioxide equivalent of all emitted greenhouse gases. A product's carbon footprint can be measured by conducting a greenhouse gas (GHG) emissions assessment. The carbon footprint refers to the comprehensive emissions generated by a given system, excluding any sequestration activities. This metric is calculated by dividing the total emissions by the functional unit, typically expressed in kilograms or litres of milk in dairy production [10]. The concept of carbon footprint is frequently employed to denote the comprehensive quantity of carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions across the entire life cycle of a given product [11]. The carbon footprint (CF) of livestock products is typically represented as a singular average measure on a national scale or within a particular production framework, such as intensive, extensive, conventional, or organic farming [12]. The carbon footprint can be broadly categorised into primary and secondary footprints. The primary carbon footprint refers to quantifying direct carbon dioxide emissions from fossil fuel combustion, encompassing activities such as domestic energy usage and transportation. The secondary footprint concept pertains to quantifying the indirect carbon dioxide (CO_2) emissions that arise throughout the entire life cycle of various products [13].Once the magnitude of a carbon footprint is determined, a strategic plan can be formulated to mitigate it through advancements in technology, improved management of processes and products, and the adoption of alternative consumption approaches.

Green House Gases

Climate change is a significant environmental issue that has been a subject of significant political and social attention. The primary greenhouse gas (GHG) in terms of food consumption is carbon dioxide (CO_2), followed by methane (CH_4) and nitrous oxide (N_2O). Food chains globally bear significant responsibility for a substantial proportion of the overall emissions of greenhouse gases (GHGs). Animal products alone accounted for 18% of global greenhouse gas emissions [14]. Global dairy production accounts for approximately 3% of the overall anthropogenic greenhouse gas (GHG) emissions [15]. The agricultural sector is responsible for approximately 13.5% of global emissions. The main sources of emissions in the agricultural sector can be attributed to methane release resulting from enteric fermentation in ruminants and rice fields, as well as nitrous oxide emissions arising from the application of nitrogen through manure and fertiliser on agricultural soil. A smaller proportion of emissions can be attributed to manure management and crop residue burning [16].

The livestock industry plays a significant role in climate change, contributing to greenhouse gas emissions directly and indirectly. Direct emissions stem from enteric fermentation and manure management, while indirect emissions result from feed-production activities. These emissions include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) [17-21]. Methane (CH_4) is the primary gaseous emission of concern originating from dairy cattle, which serves as a hydrogen reservoir within the rumen and is generated due to reducing carbon dioxide by methanogenic archaea [22]. The quantity of methane (CH_4) released from dairy waste is contingent upon the carbon, hydrogen, and oxygen content within the waste, highlighting the significant contributions of manure storage, diet, and bedding practices to overall ^{CH4} production [23]. The highest emissions are observed in straw-covered manure, while emissions decrease in untreated manure and in manure management methods involving separation, aeration, and digestion [4].

FAO [24] reported an 18% increase in greenhouse gas (GHG) emissions from the dairy sector between 2005 and 2015. This rise can be attributed to a significant growth of 30% in overall milk production, driven by an increase in consumer demand. The observed patterns in absolute emissions can be attributed to variations in animal populations and the level of production efficiency within the sector. The livestock industry, including various stages of livestock production, significantly influences climate change [25-26]. The environmental impact of dairy cattle, such as their potential adverse effects on air, water, and land, has been documented [27]. Livestock products exhibit a higher level of greenhouse gas (GHG) emissions compared to most other food sources. Emissions in the context of dairy production arise from a multitude of intricate biological processes, including methane production through enteric fermentation, methane and nitrous oxide emissions at various stages of livestock manure management, pasture and building environments, storage and subsequent spreading activities, and carbon dioxide, primarily linked to energy utilization, the manufacturing and transportation of resources, and alterations in land use and land cover [24].

Carbon emissions are generated throughout the different phases of the life cycle of food products. Pathak et al. (2010) [16] examined the emission of greenhouse gases (GHGs) from 24 food items in India, finding that the primary contributors to methane (CH_4) emissions were animal food products (meat and milk) and rice cultivation. On the other hand, food products derived from crops were found to be the main source of nitrous oxide (N_2O)

emissions. Carbon dioxide (CO_2) is released during various stages of agricultural activities, including farm operations, agricultural inputs manufacturing, transportation, food processing, and food preparation.

Several studies have examined the impact of management practices on greenhouse gas (GHG) emissions in the context of dairy farming. Gibbons et al. [28] documented a diverse range of total emissions at the farm level in the United Kingdom, ranging from 4200 to 16400kg CO_2 e/ha. Lovett et al. [29] observed that in pastoral-based dairy systems in Ireland, the estimation of carbon footprint (CF) associated with milk production can be influenced by minor alterations in management practices such as improving pasture quality, adjusting nitrogen application rates, and enhancing silage quality, have the potential to impact the overall greenhouse gas (GHG) emission estimates by approximately 5% to 6% at both the individual farm and national levels. The milk carbon footprint at the farm level is influenced by various production parameters, including animal health, calving age, and replacement rate [23,30]. The processing stage contributes to 69% of emissions, primarily attributed to the energy consumption within the processing plant. Additionally, packaging activities were found to significantly contribute to emissions, particularly about CO_2 emissions [31]. Multilayer cartons have reduced environmental effects due to minimal energy consumption and emissions during the production phase and the use of paperboard rather than polymeric materials [32]. A study by [33] found that non-returnable glass bottles exhibited the highest carbon footprint due to the production process. The returnable glass bottle was lower than the single-use glass bottle, mainly due to the distribution of emissions across eight cycles. [10] found that both PET and R-PET exhibited the smallest environmental footprints, with R-PET demonstrating an 18% reduction in footprint. The Paris Agreement, enacted in November 2016, represents a pivotal moment in international climate negotiations, signifying a commitment to a future characterised by reduced emissions. The international community has established a global objective to restrict the increase in global average temperature to less than 2°C, with additional efforts being made to restrict it to 1.5°C further. The livestock sector plays a crucial role in mitigating the effects of climate change and curbing global temperatures, necessitating a shift towards a sustainable, low-carbon, and climate-resilient development trajectory for the sector.

Calculation of Carbon footprint

Various methodologies can be used to measure greenhouse gas (GHG) emissions, including individual animal techniques, sulphur hexafluoride (SF_6), *in vitro* gas production techniques (IVGPT), and modelling techniques [34-35]. Determining the most suitable approach depends on factors such as financial implications, time constraints, precision, and experiment structure [36]. The production of dairy products involves a multifaceted system, including feed and fodder cultivation, farming practices, manure management, and transportation of animal-derived goods. Quantifying GHG emissions from all components of the dairy production system would incur significant costs and time [34]. Modelling techniques have gained significant attention for estimating emissions from extensive cattle populations at various scales, including national, regional, and organized farm levels [37-39].

Data on GHG emissions from organized dairy cattle farming systems in India is scarce, making it crucial to provide GHG emissions data for intervention measures and strategies to mitigate climate change's detrimental effects on livestock production. Life Cycle Assessment (LCA) is the most suitable methodology for evaluating sustainability of products, considering all stages that contribute to their production, including transportation, retail, consumer, and end-of-life phases. The "cradle-to-grave" life cycle assessment (LCA) offers a comprehensive approach for assessing the environmental impact of a production system, considering the potential consequences of all stages of a product or system's life cycle [40,10].

LCA is a structured, comprehensive, and internationally standardized method which involves various steps [41].

- Describe the product used by customer
- Construct the map diagram of all activities
- Annotate the diagram with various activities in detail
- Identify CO_2 equivalent emission factors for the combustion of fuels.
- Identify non-combustion-related emission factors
- Balance the product map drawn up
- Multiply CO_2 equivalent factors by quantities of inputs and outputs
- Documentation and its verification

CF calculations are typically based on annual emissions from the previous 12 months based upon the life cycle of products [13].

Reduction of carbon footprint in dairy sector

The carbon footprint (CF) of milk is subject to inherent uncertainty due to the estimation of greenhouse gas emissions, specifically nitrous oxide (N_2O) and methane (CH_4). These uncertainties arise from the complex biological processes that generate these emissions, such as soil, rumen, and manure [42]. Enhanced understanding of modelling techniques is crucial in mitigating the inherent uncertainties associated with estimating carbon footprint (CF) values for livestock products. Uncertainties in milk's carbon footprint can arise from using production data in the calculation process, which are often obtained from statistical sources or farm inventories. The presence of uncertainties in production data can be attributed to two primary factors: the insufficiency of official statistics and the disparities in management practices among farms. When analysing potential strategies to reduce milk's carbon footprint (CF), it is crucial to possess a comprehensive understanding of the uncertainties and variations present in production data [36,18].

The observed disparity in greenhouse gas emissions among dairy farms suggests the existence of a potential opportunity to mitigate carbon footprint (CF). Despite being the most effective strategy for mitigating GHG emissions, enhancing livestock productivity in the Indian livestock production system is subject to practical constraints [43,20]. Improving animal productivity encompasses various facets, such as nutrition, reproduction, health, genetics, and overall operational management within animal husbandry. Implementing these practices and technologies can substantially decrease the emission intensity associated with milk production [24] .

Feed and Feeding Management

Enteric fermentation is the primary source of CH_4 emissions in cattle milk production at the farm level. Enhancing the quality of feed, particularly roughage, can potentially decrease enteric methane production (CH_4). Factors such as ingestion and chemical makeup of carbohydrate, feed retention duration, fermentation pace, and rate of methanogenesis can affect the quantity of ^{CH4} generated [44]. The manipulation of feed digestibility and chemical composition results in a modification of the relative amounts of volatile fatty acids (VFAs), with propionate, butyrate, and acetate being the most abundant VFAs [45]. The significance of this alteration in VFA proportion lies in the fact that propionate serves as a hydrogen sink. Consequently, transitioning from the production of acetate and butyrate to propionate will result in the utilisation of reducing equivalents, thereby aiding in the maintenance of pH equilibrium within the rumen [46]. Various modified feeding strategies can be employed to achieve a general decrease in CH_4 emissions or a change in VFAs. Feedstuffs with higher energy density or greater digestibility contribute to increased energy availability for the animal, producing lower levels of CH_4 through fermentation [45]. An augmentation in the starch content of the dietary regimen leads to an accelerated fermentation process of these feed materials, consequently causing a reduction in methane (CH_4) emissions [4]. Diets with higher concentrations of legumes, such as lucerne, may reduce CH_4 emissions when compared to diets primarily composed of grass forage [47]. The age at which forage is harvested has a notable influence on emissions. The inclusion of lipids in the diets of dairy cattle has been shown to have the potential to reduce enteric emissions, in addition to modifications in the composition and ratio of forage or concentrate [20]. In addition to modifications made to the composition of dietary ingredients, there are also dietary additives that can potentially mitigate enteric emissions. One potentially effective approach for reducing CH_4 emissions is the addition of a methanogenic inhibitor known as 3-Nitrooxypropanol (3-NOP) to animal feed. This compound bears a structural resemblance to methyl-coenzyme M and functions by interacting with methyl-coenzyme M reductase (MCR). 3-NOP could imitate methyl-coenzyme M and selectively bind to the active site of MCR. As a result, this binding inhibits the enzymatic activity of MCR, leading to a reduction in the production of CH_4 [48]. In vitro experiments conducted by [49] reported a decrease of up to 95%, while in vivo investigations by [50] observed a reduction of 84%. However, the efficacy of this molecule in various dairy breeds remains to be assessed, and a comprehensive understanding of its potential side effects is still lacking.

Nitrates also have considerable potential in mitigating methane emissions. In a study by [51], nitrate supplementation at a rate of 21 grams per kilogram of dry matter intake (DMI) resulted in reduction of methane (CH_4) emissions, which persisted at 16%. In a study conducted by [52], it was observed that the introduction of nitrate supplementation at a rate of 21 g/kg DMI resulted in a decrease in ^{CH4} emissions from 363 g for control animals to 263 g for animals receiving the supplement. A meta-analysis revealed a consistent decrease in methane emissions in both in vitro and in vivo investigations. Condensed tannins, secondary phenolic compounds, are found to deter herbivores and contribute to nitrogen accumulation in plants [53]. Ingestion of tannins by dairy cattle results in protein binding in the rumen, reducing protein degradation and improving protein flow to the intestines. The origin of tannins has been found to significantly impact the reduction of methane (CH_4) emissions from dairy cattle [44]. Studies have shown that adding *Hedysarum coronarium* species at a rate of 27 g per kilogram of dry matter intake (DMI) led to a reduction in methane emissions from dairy cattle [54]. Essential oils, which are volatile components found in plants, have been investigated for their antimicrobial properties. Studies have shown that using essential oils can decrease methane production by inhibiting the growth and energy metabolism of specific bacteria and archaea, including methanogens [55]. A total of over 250 essential oils have been discovered, consisting of terpenoids, aliphatic hydrocarbons with low molecular weight, alcohols, acids, aldehydes, acrylic esters, N, sulphur, coumarins, and phenylpropanoid homologs [44]. In vitro screening on essential oils has shown that 35 were observed to have a positive impact, but only six showed significant reductions in emissions without adversely affecting digestibility [56]. Studies have also shown that commercially available blends of essential oils, such as Agolin SA, can mitigate enteric methane emissions. However, these effects are not consistently sustained over a prolonged period [57]. A recent study by [58] suggests that the carbon footprint value tends to decrease as milk production per cow increases and the proportion of pasture in the cow's diet increases. Dairy farms that primarily rely on pasture as their main feed source typically exhibit a diminished carbon dioxide (CO_2) emission footprint, attributed to reduced fossil fuel consumption and limited reliance on externally sourced feed [59]. Numerous potential approaches exist to mitigate enteric emissions by implementing modifications to nutrition strategy and composition.

Manure Management

In the context of solid storage, the collection of fresh manure occurs in unconfined piles over an extended period. This process facilitates the decomposition of organic matter by microorganisms, producing greenhouse gases (GHGs). It is worth noting that the introduction of aeration has the potential to decrease methane (CH_4) emissions while increasing nitrous oxide (N_2O) emissions [60-61]. The implementation of solid storage is a prevalent method for managing manure in the context of dairy cattle farming in India. Moreover, the implementation of the manure management system resulted in a significant decrease of 87.42% in methane (CH_4) emissions and a reduction of 16.97% in nitrous oxide (N_2O) emissions originating from manure management practices [62].

Fertilizer Management (Manure and Commercial Fertilizer)

Synthetic fertilisers, particularly in pasture-based systems, constitute a noteworthy contributor to emissions during the on-farm stage. These emissions are primarily attributed to the release of nitrous oxide (N_2O) from nitrogen-based fertilisers [10]. Reducing the application of fertiliser and substituting it with the utilisation of manure for biogas production has been identified as a potential strategy for mitigating carbon emissions [63-64]. According to [65], the utilisation of Best Available Technology (BAT) in the production of synthetic fertilisers, specifically ammonium nitrate, results in a significantly reduced carbon footprint (CF) compared to traditionally produced fertilisers. Specifically, BAT-produced synthetic fertilisers exhibit approximately half the CF of their traditionally produced counterparts. Utilise commercially manufactured fertilisers produced through environmentally sustainable practices, characterized by a minimal carbon footprint. Apply these fertilisers during the optimal timing and employ cutting-edge technologies for efficient distribution.

Energy use at the farm

The utilisation of alternative energy sources such as solar energy, biogas derived from effluent treatment plants, biomass energy, and biomass gasifiers has the potential to mitigate carbon footprint [66]. The potential for reducing carbon footprint can be significantly enhanced through the implementation of various strategies such as reducing transportation energy, increasing the utilisation of sustainable energy sources like wind energy and biofuel, optimising the use of packaging materials, and carefully selecting appropriate fuels [67,13]. According to a study conducted by [68], the collective emissions of carbon dioxide equivalent (CO_2e) resulting from the disposal of milk and dairy products at the consumer level amount to approximately 63 million metric tonnes globally. The extension of the shelf-life of products and preventing food waste play a crucial role in mitigating greenhouse gas emissions in the post-dairy chain [69].

Housing management

The emissions profile exhibits variations in nations where animals must be sheltered due to climatic circumstances. According to [70], using fuel and crop feeds can contribute to more than 10% of the carbon footprint associated with milk production. Additionally, [40] have found that methane (CH_4) emissions may account for less than 50% of the total carbon dioxide equivalent emissions, particularly in confinement dairy systems.

Animal Health and Reproductive Performance

The implementation of herd structure management strategies aimed at mitigating the presence of non-productive animals by enhancing animal and herd fertility and reproduction represents a viable method for decreasing emissions per unit of milk and enhancing the financial viability of dairy operations. Enhanced animal reproductive performance is anticipated to yield higher herd productivity, consequently reducing the emissions of CH_4 and N_2O per unit of output. The phenomenon of reduced fertility in livestock production systems has been found to have a direct correlation with increased greenhouse gas (GHG) emissions.

Livestock producers are compelled to maintain a higher animal population per unit of production and retain a larger number of male and female replacement animals to sustain herd size due to the limited fertility observed among the livestock [71-73]. Consequently, implementing this practice will result in elevated greenhouse gas emissions within the dairy farm. The baseline and proposed intervention packages resulted in total greenhouse gas (GHG) emissions of 537,167.06 kg CO_2/year and 393,944.61 kgCO_2/year for adult females, respectively. This represents a reduction of 26.66% in GHG emissions. The aggregate greenhouse gas emissions from the utilisation of replacement females in both the baseline and proposed interventions packages were recorded as 183,927.54 kg CO_2/year and 120,375.34 kgCO_2/year, respectively. This indicates a reduction of 34.55% in emissions. The factors such as nutritional status, micronutrient deficiencies, service period, the timing of artificial insemination, dry period, method of estrus detection, and method of pregnancy diagnosis are key factors that determine animal fertility [74]. Therefore, enhancing animal reproductive performance will result in a reduction in greenhouse gas (GHG) emissions. Hristov [75] propose that mitigating greenhouse gas (GHG) emissions can be achieved through the implementation of strategies aimed at reducing animal mortality rates and enhancing reproductive performances. These strategies focus on increasing herd productivity, improving animal health, and promoting longevity.

The mitigation of diseases and parasites tends to decrease emissions intensity due to the enhanced productivity of healthier animals, leading to a reduction in emissions per unit of output. According to [72], there is a significant increase in the emission values of ^{CH4} and N2O when the productive potential is diminished due to poor health.

Conclusion:

Daily, there is a discernible rise in greenhouse gas (GHG) emissions, primarily attributed to population growth, consumption patterns, and production volumes. Notably, a significant contributor to this increase is the lack of awareness regarding the adverse impacts of these emitted gases on both present and future generations. A methodology has been developed for the dairy sector that enables the quantification of the carbon footprint associated with dairy products. The primary goal of carbon footprint calculation is to develop a strategic course of action to mitigate greenhouse gas emissions. To mitigate greenhouse gas (GHG) emissions from the dairy sector, it is imperative to disseminate knowledge to dairy farmers, optimise farming systems, minimise energy consumption, and implement effective waste management practices. Therefore, the Indian dairy cattle farming system must address key intervention areas such as feeding management, animal health and reproductive performance, and manure management. This is crucial to ensure the long-term sustainability of the livestock production system, particularly in light of the changing climate scenario.

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