International Journal of Veterinary Sciences and Animal Husbandry 2025; SP-10(10): 154-161

International Journal of Veterinary Sciences and Animal Husbandry

ISSN: 2456-2912
NAAS Rating (2025): 4.61
VET 2025; SP-10(10): 154-161

www.veterinarypaper.com
Received: 02-08-2025
Accepted: 05-09-2025

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Cow dung-Precursor for climate change a review

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DOI: https://www.doi.org/10.22271/veterinary.2025.v10.i10Sc.2902

Abstract
Livestock waste especially cow dung, which is a readily available, renewable and bio-resource, can be beneficial and harmful both depending on how it is managed. Improper treatment or anaerobic digestion of cow dung produces greenhouse gases: CO_2, CH_4, and others nitrous oxide. These gases trap infrared radiation, warm the atmosphere, contribute to majorly to global warming, air pollution and climatic change. Improper management also results in soil and water pollution through the release of harmful nitrogen compounds. However, when cow dung is properly managed and utilized as a bio resource rather than waste, it can be transformed into valuable by-products such as biogas, biochar, compost, and organic initiatives such as GOBARDHAN and Godhan Nyay Yojana to ensure the proper management of cow manure. This not only provides renewable energy and organic fertilizers but also enhances soil fertility and promotes environmental conservation.

Keywords: Cowdung**,** management, greenhouse gases, emission, climatic change

1. Introduction

Among various sources of climate change, the livestock and dairy farms are consider major source of greenhouse gas emissions, thereby raising the level of gases in the atmosphere. It is a significant contribution to global warming and climate change. The greenhouse gas CH_4 significant quantity comes from livestock especially cattle by their enteric fermentation, a microbial digestive process. Bandara, et. al. shown that the significant amount of N_2O emits due to stored manure or on land by the process of nitrification in which ammonia with microbes produce nitrate and next, de nitrification process produces N_2O **(**Bačėninaitė et al., 2022; Bandara, et al.,2025) [1, 2]. In global warming, these gases' impact is greater than the carbon dioxide (CO_2).The emission of these gases due to livestock especially cattle has become a significant target in efforts to cut down the climate changes. The global annual livestock release is roughly equivalent to seven billion tonnes of CO_2. The contribution of Cattle in these emissions are nearly two-thirds (Bačėninaitė et al., 2022; FAO, 2017) [1]. Researchers are of the view that the emission of Methane in the dairy sector is greatly underestimated. Using advanced techniques of measurement methods found that half of the total live stock's methane emission is contributed by the manure (Ward et al., 2024; Cárdenas et al., 2020) [4]. The major source of CH_4 is storing the liquid manure (slurry) in lagoons and open ponds. This method of storage produces more methane in summer. So, this is one of the significant contributors to the overall climate impact of the agriculture system which results in increase of greenhouse effect on the atmosphere (Ward et al., 2024; Ambrose et al., 2023) [4, 6]. It is found that in certain regions including the USA the methane emission due to manure production is more rapid than the enteric fermentation process, (Beck et al., 2023) [7]. Based upon these studies which suggest the need of better monitoring of emitted gases, adoption of sustainable feeding, breeding and waste management practices. To reduce climate impact, the integrated, multi sectoral approaches can convert livestock waste into biogas for renewable energy and organic fertilizer for enhancement of soil quality.

Cow manure is both a natural resource and a by-product of agriculture. Professionally managed, it can provide organic fertilisers, clean fuel biogas, and useful biomaterials. Unmanaged cow poo can spread illness and cause pollution. Greenhouse emissions like CO2 and methane may be reduced as a result of producing biogas from cow manure. By reducing reliance on fossil fuels like petrol, kerosene and LPG, biogas produced from cow dung lowers further CO2 emissions into the atmosphere (Ratminingsih & Jumadi, 2021; Luo et al., 2024) [8, 9].

Studies have demonstrated that turning cow dung into biogas in well-designed community biogas systems can reduce carbon emissions by as much as 3.77% (Luo et al., 2024; Nleya et al., 2024) [9, 10]. Apart from energy production use, cow dung when converted into biochar offers agricultural and environmental benefits. Biochar is a stable, nutrient rich material that improves soil structure, enhances water retention, boosts crop yields, and improves nitrogen use efficiency (Park et al., 2024; Kukwa et al., 2025) [12, 13]. Biochar plays a significant role in carbon sequestration, where stable form in biochar the stable carbon in biochar stays in soil for a long period, remaining in the soil for long periods reducing CO_2 released into the atmosphere and mitigating climate change. The beneficial microorganism in cow dung improves soil fertility, promotes climate friendly and organic farming practices (Li et al., 2023) [14]. Additionally, cow dung has been shown to be beneficial for socioeconomic growth. Organised cow dung management can generate renewable energy, lessen local environmental pollution, facilitate resource recovery, stop deforestation, and promote rural livelihoods, according to programs like GOBAR-DHAN and Godhan Nyay Yojana in India. (Sahdev et al., 2024; Shaibur et al., 2021) [74, 99].

Nitrous oxide, ammonia, and greenhouse gas emissions from livestock manure are controlled using integrated manure management techniques. The acidity of the slurry lowers the formation of methane, nitrous oxide, and ammonia. The dietary modification strategy involves altering food to reduce phosphorus and nitrogen levels in order to reduce emissions. Emissions can be reduced by the manure coverings. The creation of biogas is favoured by the anaerobic digestion method. These tactics encourage the recycling of nutrients. (Hou et al., 2015) [17]. When manure is managed properly, it gives many useful products such as biogas and compost. Bio gas is a source of energy and compost increases fertility of the soil. Adoption of these methods provide rural employment and reduce the impacts of climate change (Brahmi et al., 2024) [18].

The potential of cow dung as a sustainable way to mitigate climate change is covered in this paper, along with how it can be used to generate renewable energy, boost soil fertility, and improve rural livelihoods. This paper offers a thorough summary of cow dung management strategies, current technical developments, problems, and potential areas for future research. It seeks to establish cow dung as a key component of rural development and climate-friendly farming.

2. Composition and Properties of Cow Dung*

Cow dung is versatile in nature. its thermal, agriculture and environmental properties found in reducing greenhouse gases emission, biogas generation, organic fertilizers improving soil fertility, building material and many others sustainable applications. Cow dung contain high moisture content, (65-75%), carbon-to-nitrogen (C: N) ratio of approximately 20-30:1, about 3% Nitrogen 2% Phosphorus and 1% potassium **(**Makumbi et al., 2025; HomeBiogas, n.d.) [19]. Its pH is neutral or near neutral (~6.5-7), which is helpful in microbial activity during anaerobic digestion (Makumbi et al., 2025; HomeBiogas, n.d.) [19]. Anaerobic digestion produces gases which consists of 50-75% methane (CH_4), 25-50% carbon dioxide (CO_2), with traces of hydrogen sulfide (H_2S), water vapor (H_2O), and occasionally mercaptans, oxygen, and nitrogen (HomeBiogas, n.d.). Cow dung has high energy potential about 1 kg of it can produce 15-40 litres of biogas per day, depending on how it's treated. A single cow produces around 29.5 kg of manure, which can yield 250-500 litres of methane daily (HomeBiogas, n.d.). Biogas production process takes around a week. Cow dung breaks down slowly, when mixed with carbon rich waste or poultry manure, both quantity and quality of biogas gets improved (HomeBiogas, n.d.). Thermally, dairy cattle manure exhibits specific heat values ranging from 1.9925 to 3.606 kJ kg^{-1} $°C^{-1}$, thermal conductivity from 0.0901 to 0.6814 Wm^{-1} $°C^{-1}$, and thermal diffusivity from 1.13 to 2.94 × 10^{-7} m^2 s^{-1}, with moisture content exerting a stronger influence than temperature (Nayyeri et al., 2009) [21]. Beef cattle manure shows decreasing specific heat from 4.13 kJ kg^{-1} $°C^{-1}$ at 1.42% total solids (TS) to 1.40 kJ kg^{-1} $°C^{-1}$ at 99.4% TS, while thermal conductivity varies from 630 mW m^{-1} $°C^{-1}$ at 2.8% TS to 60.4 mWm^{-1} $°C^{-1}$ at 95% TS, and thermal diffusivity depends on total solids content (Chen, 1983). These characteristics make it suitable for use in thermal insulation, biocomposites and building materials. Incorporating 3-9%% cowdung powder into glass polyester hybrid composites reduces thermal conductivity and enhances thermal resistivity (Reddy et al., 2013). Similarly, adding 0-20%% cowdung powder to soil-based building materials improves combustion (from 0.58% to 1.03%) and heat capacity (from 3.35 Cal/oC to 5.01 Cal/oC), with 15-20% being the optimal stabilization range for thermal performance (Zievie et al., 2025) [24]. Cow dung is additionally employed as an insulating material in building construction, where it reduces heat transfer, enhances thermal resistance, and aids in maintaining stable indoor temperatures **(**Kumar et al., 2020) [25]. Upon combustion, cow dung releases organic vapors, nitrogen-containing compounds, and intermediate-volatility organic compounds, which collectively account for approximately 12.6-39.3% of total emissions (Wang et al., 2025) [26]. Furthermore, plant growth-promoting microorganisms found in cow dung facilitate phosphate solubilisation for plant utilisation. These bacteria generate siderophores and the natural growth hormone IAA. These have antifungal effects by aiding the plant in absorbing iron. Cow dung can be utilised as a natural biofertilizer to promote sustainable and healthful farming because of these advantages. (Sagar et al., 2025) [27].

3. Environmental Implications of Cow Dung Mismanagement

3.1 Greenhouse Gas Emissions

Poor management of cow dung led to environmental consequences mainly due to greenhouse gases. Waste products from dairy and swine farms emits huge amounts of methane (CH_4), over 80 times more potent than CO_2, mainly from wet storage systems such as lagoons and pits, contributing approximately 1% of U.S. national emissions (Badzmierowski et al., 2024) [28]. Globally, about 60% of methane is caused by anthropogenic emissions, and about 40% from natural sources, with manure management contributing roughly 7% of agricultural methane emissions (Bessagne et al., 2024; Ferreira, F., & McCabe., 2024) [29, 30]. Methane contributes to roughly half of the 1.1°C global temperature rise since pre-industrial times and has a strong short-term warming potential (Ferreira, F., & McCabe., 2024) [30]. In addition, nitrous oxide (N_2O) emissions occur primarily after manure is applied to land as fertilizer through microbial nitrification and denitrification processes Low quality of manure management also produces black carbon emissions, leads to nutrient losses, contaminates and poses risks to cow health and milk quality (Hassan et al., 2022; CCAC, 2024) [31].

Mitigation strategies should include separation processes like aeration, acidification, and anaerobic digestion, which reduce methane emissions while improving odour control, fertilizer value, and handling (Badzmierowski et al., 2024; Streeter, 2024) [28, 33]. Diet manipulation to lower excreted nitrogen and degradable carbon can reduce both CH_4 and N_2O emissions, and manure injection, cover crops, and urease or nitrification inhibitors can further control emissions (Montes et al., 2013) [24]. Innovative approaches, a direct mixing of red algae (Asparagopsis taxiformis) to cow manure results in reduction of methane emissions nearly 44%. This approach doesn't affect food safety (Gramling. 2023) [95]. Anaerobic digestion, a biochemical process in absence of oxygen in manure, produces a beneficial renewable biogas and degrades harmful organic matter.this process is to be monitored for by product (Neri et al, 2023) [36]. Global annual methane production is around 120 million tonnes of methane annually and 3.3 billion tonnes of CO_2. The emission intensity is the amount of methane per kg of milk or meat. It is found that in low income countries the emission intensity is 6-16 higher. The increase in emission is due to less efficient production systems (Ferreira, F., & McCabe, 2024) [30]. Direct methane reduction with improved efficiency can be achieved by using pasture management, better feeding, and breeding. The global warming can be limited upto 1.5 °C by using improved manure handling, and anaerobic digesters (Hristov, A. N. 2024; Arndt et al., 2022) [37, 38]. The Climate and Clean Air Coalition (CCAC) with its partners SEI, FAO, ILRI, Wageningen University and CATIE. Wageningen University approach on reduction of short-lived climate pollutants, by optimization of nutrient recycling, and capturing methane for energy and fixing manure management in livestock policies. By providing training, knowledge-sharing platforms and technical assistance for these programs in Asia, Latin America and Africa is resulted into, reduction of greenhouse gas emissions and enhanced sustainable livestock production (CCAC, 2024).

3.2. Air Pollution

When cow dung is used as cooking fuel in rural India by through combustion releases high level of toxic volatile organic compounds (VOCs).Thus the use as cooking fuel it contributes in Air Pollution a raise levels of particulate matter (PM2.5).The cow dung as cooking fuel, even used by by fewer households surpasses emissions from wood and other biofuels, households (Brown, 2024; Park et al., 2013; Wikipedia, 2025) [39, 40, 41]. Study of 2020 has shown that approximately 1,600 gigagrams of PM2.5 was produced by dung stoves. Used by Less than 10% households in comparison, it is found to be 17% higher than wood stoves and half of residential emissions. There were 1.6million deaths from household air pollution in 2019 due to household exposure to smoke at a level of PM2.5 resulting in decreased respiratory, cardiovascular diseases and premature mortality (Brown, 2024) [39]. The Government of India took initiatives such as the Pradhan Mantri Ujjwala Yojana which have successfully phased out kerosene and coal. Due to the cost barriers, its impact on reduction of biofuel have had limited impact (Swain & Mishra., 2020) [42]. Ranjan & Singh., 2020) [43]. The cow dung and agricultural waste are being converted into cleaner-burning methane using Mitigation strategies.

Among numerous organic species, unique traces of cholestanol and coprostanol, more reactive VOCs that interact with hydroxyl radicals, are released upon combustion of Cow dung. In comparison of wood cow dung produces 3-4 times more secondary organic aerosol. Their high nitrogen content influences health and environmental impacts (Loebel Roson et, 2024; Wikipedia, 2025) [45, 46]. Major sources of ammonia, methane, and PM2.5, besides the household fuel, are livestock operations, particularly Concentrated Animal Feeding Operations (CAFOs).The emission of Ammonia contribute to secondary PM formation, which results in respiratory issues, and premature deaths (Burns et al., 2023; Bleizgys & Naujokienė, 2023; Rocha, 2021) [47, 48, 49]. Liquid manure in comparison with solid manure emits more ammonia. The emission can be reduced by adopting management practices,such as manure flushing, composting, bedding and anaerobic digesters that also generate biogas (Rocha, 2021; Pineda & Chea, 2024) [49, 50].

Cow manure, using Anaerobic digesters, converts it into methane-based biofuel and mitigates emissions of greenhouse gases and also an alternative to fossil fuel. These techniques are also responsible for local ammonia exposure and odors for nearby communities. This, in turn, creates the problem of environmental justice concerns **(**Pineda & Chea, 2024) [50]. In California, there was a reduction of approximately 10 million metric tons of CO_2 equivalent emissions in 2022.despite it the residents of nearby dairy have reported respiratory issues and other health impacts (Pineda & Chea, 2024) [50]. Significant contributions to PM2.5 due to the release of methane, VOCs and ammonia are cow dung and livestock. This is a major concern of health risks of low income and poorly ventilated communities. Practicing Mitigation strategies which are biogas production, manure management and cleaner cooking fuels, may limit impact on the environment while environmental justice considerations remain critical.

3.3. Water Contamination

Nowadays, Intensive dairy cattle systems have become a source of modern milk production based upon high animal densities and concentrated feeding operations. This type of dairy cattle systems pose environmental challenges in the form of nutrient pollution. The excessive excretion of nitrogen (N) and phosphorus (P) in manure is also a source of significant nitrogen (N) and phosphorus (P) pollution. Unmanaged nutrients can accumulate in soil and leach into the water body. The water body has an excessive amount of these nutrients that disrupt the aquatic ecosystems and lead to water eutrophication (Biagini & Lazzaroni, 2018) [51]. Won et al. study shows that manure nutrients accumulate in soils and contribute to eutrophication (Won et al., 2016) [52]. The manure is valuable for soil enrichment; it also causes water pollution, if mismanaged can cause serious water pollution. Manure also have pathogens like E. coli and Salmonella into the surface and can percolate to groundwater. Existence of these pathogens can pose public health risks (Alegbeleye & Sant'Ana, 2020; Abdugheni et al., 2023) [53, 54]. The runoff Nutrients like nitrogen and phosphorus manure trigger the process of eutrophication in the water body. These nutrients excreted in manure if mismanaged lead to serious ecological consequences like algal blooms, and oxygen depletion in aquatic systems. The cow dung harbouring pathogens such as E. coli, Salmonella, and Cryptosporidium spp., can pose health risks to humans and water quality (Chourasiya et al., 2021; Nguyen et al., 2025; Munshi et al., 2019) [55, 56, 57]. The ammonia is also a source of pollution from livestock waste and creates aquatic toxicity and nitrate leaching, endangering the health of humans and animals. Some manure management practices such as composting, introducing vegetative buffer strips and implementation of de-nitrification processes significantly reduce nutrient loading. The directives of Regulatory Bodies for safeguarding the environment play a crucial role in mitigating the impacts of intensive dairy farming. The European Union's Nitrates Directive and the United States' Clean Water Act emphasize the adoption of sustainable agricultural practices. These directive and regulations mandate measures such as controlled manure application, buffer zones near waterways and prevent runoff and leaching of nutrients phosphorus and nitrogen. These regulations aim for safeguarding water quality and aquatic ecosystems.

4. Cow Dung and Climate Change Interconnection

Cow dung management is of utmost importance as it plays a role in the interconnection between livestock production and climatic change. Mismanagement of cow dung leads to the emission of methane and N_2O, global gases responsible for global warming and thus climatic change. Methane, a potent greenhouse gas much stronger than CO_2, is released during anaerobic decomposition of cow dung. The organic material present in cow dung, when stored in slurry piles, lagoons, or left stagnant, is decomposed by methanogenic bacteria under no or little oxygen conditions (Earth.Org, 2024). N_2O is released during the processes of nitrification and denitrification. Microbes break down the organic matter present in cow dung, releasing N_2O but also producing useful organic fertilizer through composting. During composting, organic nitrogen is converted into ammonium (NH_4^+), and part of it is lost as ammonia (NH_3), N_2O, or nitrogen gas (N_2). Although N_2O is released during composting, it is proven to be an eco-friendly method for recycling animal waste into fertilizer (Maeda et al., 2011) [59]. Globally, agriculture and livestock production contribute 12% greenhouse gas emissions apart from fossil fuels (Symeon et al., 2025) [60].

Proper handling and storage of manure can reduce the emission of greenhouse gases to a great extent. One should adopt proper management practices, not only lowering NH_3, N_2O, CH_4, and odour emissions, but also methane reduction during storage. Studies by Amon and others conclude that lowering the content of dry matter amounts of easily degradable organic material in slurry can lower methane production. When there is less organic material available, less breakdown by microbes will occur and hence less methane production (Peterson et al., 2013; Amon et al., 2006) [61]. Centralized livestock systems are better handling the manure and use biogas plants more effectively with less methane production. But proper planning is essential for the reuse of nutrients from manure. Farm size greatly affects greenhouse gases emission. Large farms with liquid manure which is untreated for a longer period if untreated release a lot of greenhouse gases in comparison to small farms with solid manure that are treated every day (Aguirre-Villegas & Larson, 2017) [63].

Poor storage and low-oxygen conditions in cow dung can cause more release of greenhouse gases, loss of important nutrients, and cause water pollution. To solve these issues, initiatives like FAO, SEI, ILRI, CATIE, Wageningen University, and the Climate and Clean Air Coalition are working together through the Livestock and Manure Management Initiative. This program supports sustainable practices by supporting farmers to use better, eco-friendly methods that reduce harmful gases, turn methane into renewable biogas, and recycle nutrients to improve crop growth (Teenstera et al., 2014; Climate and Clean Air Coalition, 2024) [66, 32]. Technologies like anaerobic digesters help prevent methane from entering into the atmosphere by converting it into renewable energy, heat, cooking fuel, and organic fertilizers (Teenstera et al., 2014; U.S. EPA, 2024) [66]. Farmers use methods like solid liquid sequestration and composting for cutting methane emission and improving soil quality. They use cow dung as a valuable resource instead of as a waste (Rocha, 2021) [49]. Research studies show that CH_4 and NO_2 emissions from livestock manure rose by about 50% between 1961 and 2010, highlighting the urgent need for better manure management practices. This is because these global house gases significantly contribute to global warming and thus majorly to climatic change (University of Maryland Extension, 2023). In many regions across Africa, Latin America, and Asia, supportive policies and training programs are helping farmers adopt better dung management, reducing emissions and strengthening resilience to climate impacts (Teenstera et al., 2014 [66]; Climate and Clean Air Coalition, 2024). Ultimately, cow dung often viewed as waste represents both a challenge and an opportunity: mismanagement leads to harmful methane and nitrous oxide emissions, but when used for biogas production, composting, and soil health improvement, it becomes a powerful tool for climate action and sustainable agriculture.

5. Sustainable Utilization Pathways of Cow Dung.

Cow dung is increasingly recognized as a valuable bioresource accounting for more than half of the total manure produced (Li et al., 2021). It has various sustainable utilization pathways such as renewable energy production. One major use is the generation of biogas through the anaerobic digestion process, which is used for cooking, electricity, agricultural fertilizers, reducing greenhouse gas emission, decreasing dependence on fossil fuels and other needs. However, this process also results in the release of greenhouse gases that brings climatic change by global warming (Jameel et al., 2024) [69]. Biogas production can be improved through optimization of substrate composition, temperature, pH allow bacteria to work efficiently, and mixing cow dung with crop or food residues for balancing nutrients and enhance gas production (Sidra et al., 2018; Kadir et al., 2024) [89, 71]. Biogas slurry is nutrient rich especially in (NPK) by product of anaerobic digestion has multiple uses. These includes hydroponic nutrient solution for lettuce growth when enriched with CO2, organic fertilizer for improving soil productivity and fertility (Liang et al., 2023; Mgxaji et al., 2025) [72, 73]. Policy initiatives such as GOBAR-DHAN and Godhan Nyay Yojana promote the conversion of cow dung into compressed biogas and organic fertilizers, thereby supporting rural development and energy sustainability (Sahdev et al., 2024) [74].

Cow waste have long been recognized in India as natural pesticide and manure, and recent research confirms their significant role in sustainable agriculture. Rich in essential nutrients, organic matter, and beneficial microorganisms, cow dung enhances soil fertility and plant growth, while cow-urine provides nitrogen, minerals, and natural pest-repellent properties. Their use promotes eco-friendly farming by reducing reliance on synthetic fertilizers, supporting composting, improving microbial activity, and converting fallow land into fertile soil. Beyond fertilization, cow dung serves as a bio-resource for renewable energy, such as biogas and dung cakes, and its microorganisms offer potential applications in agriculture, medicine, and environmental management. Overall, cow dung and urine present cost-effective, sustainable solutions to increase productivity, maintain soil health, and foster environmentally responsible farming practices. In agriculture, cow dung serves as a natural fertilizer and soil conditioner, improving soil fertility, nutrient availability, plant growth and many more. (Patra & Bharti., 2024; Raj et al., 2014; Gupta et al., 2016) [97, 96, 77]. It can be processed into vermicompost, which enhances seed germination, vegetative growth, and overall crop productivity (Rajeshkumar et al., 2015; Shafique et al., 2023; Fakhruddin & Gupta, 2020) [78, 79, 80]. Additionally, cow dung is a key component in biofertilizers, offering an alternative to man-made fertilizers (Saxena & Sandhwar; Gupta et al., 2016) [77]. From an environmental perspective, proper management of cow dung reduces methane emissions and pathogen spread from slaughterhouses and farms (Olaoye et al., 2018; Yerima et al., 2016, 2019) [81-, 82, 83]. Treated cow dung can also function as an eco-friendly adsorbent for the removal of organic pollutants such as dyes from wastewater (El-Rayyes et al., 2025) [84]. Cow dung further contributes to sustainable product development and industrial applications. It is used in the manufacture of eco-bricks and cow dung concrete as a low-cost, environmentally friendly alternative to conventional construction materials (Thanki & Gohil, 2022; Hilal & Magudeaswaran., 2022) [85, 86]. Other applications include eco-products, 3D structures, and herbal mosquito repellents, which are affordable, recyclable, and can create employment opportunities in rural areas (Kunjar, 2022; Sharma et al., 2017) [87, 88]. Moreover, cow dung harbors diverse microorganisms capable of producing beneficial metabolites, which can be harnessed for bioenergy, industrial processes, and environmental pollutant management (Gupta et al., 2016; Saxena & Sandhwar) [77]. Collectively, these applications highlight livestock wasteeek as a multifunctional, renewable resource that promotes clean energy, sustainable agriculture, environmental conservation, rural development, and low-cost, eco-friendly innovations.

6. Challenges and Limitations

Livestock waste, an easily obtainable and multipurpose bioresource has been used traditionally in India for a very long time across agriculture, fuel, environmental management, and pollution control (Gupta et al., 2021) [90]. It is useful in agriculture, medicine, and industry due to the presence of abundant microorganisms. These microorganisms are capable of producing useful metabolites and enhancing soil fertility through the process of phosphate solubilisation and growth hormone production (Gupta et al., 2021; Ananno et al., 2021) [90, 91]. Cow dung has many advantages like energy production, killing harmful pathogens, converting organic waste into good quality fertilizer, protecting soil, water and vegetation, supporting livestock and crop production and reduction of greenhouse gas emissions. However, biogas production technology is small and incomplete and leads to change in temperature in urban areas and is often expensive (Jameel et al., 2024) [69]. Biogas is not always sustainable; it leads to the production of bio-methane using digesters and poses a negative effect in nearby communities. It not only increases the financial burden on farmers but also supports the expansion of harmful industrial farming (Gittelson et al., 2022) [93]. In India, using cowdung as cooking fuel release large amount of particulate matter and methane in the atmosphere which respiratory and cardiovascular health risks. So new Innovative approaches are adopted for eample, such as adding red algae to the cow faeces, show great promise in reducing the methane emissions (Sussan et al., 2014; Gramling, 2023) [94, 95]. Overall, cowdung use in energy, agricultural and environmental applications proves it to be a valuable sustainable resource. Beyond these eco-friendly applications it is also useful in industrial processes and in microbial production of enzymes, chemicals, and antibiotics (Gupta et al., 2021; Ananno et al., 2021; Pineda & Chea, 2024; Brown, 2024; Gramling, 2023) [90, 91, 92, 39, 95].

7. Future Perspectives and Research Needs Submission

Futuristic research approach is to work on how to reduce CH_4 emissions from livestock. Dietary interventions are regarded as one of the straight forward and cost effective approach to potentially reduce ruminant methane emissions upto almost 70% (Tseten, et al., 2022) [98]. Additionally, need to optimize the use of cow waste as a bio-resource to enhance fertility of soil, promote microbial activity, and improve nutrient availability and crop yields (Raj et al., 2014; Patra & Bharti, 2024; Gupta et al., 2016) [96, 97, 77]. Research studies can also investigate the potential of biogas production from cow dung as a sustainable household energy source, along with the effective utilization of nutrient-rich residues to replace chemical fertilizers (Yerima, 2016; Shaibur et al., 2021) [82, 99]. Furthermore, exploring novel applications, such as eco-friendly building materials and safe sanitation practices using cow dung, could broaden its sustainable and environmentally beneficial uses (Julita et al., 2022; Material District., 2023) [100, 101]. Overall, cow dung plays a dual role: mismanagement can contribute to air pollution and GHG emissions but also offers sustainable solutions in energy, agriculture, and environmental management when utilized responsibly (Sahdev et al., 2024; Raj et al., 2014; Patra & Bharti, 2024) [74, 96, 97]. In order to maximize benefits and reduce environmental impacts from cow dung, effective strategies should be put into practice. These include biogas production to provide renewable energy and reduce methane emissions, organic fertilization to improve soil quality, and dietary management of livestock to lower enteric methane production. These strategies have been proven effective in minimizing environmental impacts, enhancing waste management, and reducing the risk of air pollution.

Conclusion

Emission of harmful greenhouse gases like CO_2, CH_4 and NO_2 from cow dung has become a threat to global-warming and climatic change. The potential of methane is far stronger than CO_2. Cow dung storage in pits, lagoons, or slurry tanks provides anaerobic conditions for decomposition, and this results in the production of methane and CO_2. Cow dung contains nitrogen-rich compounds, and their nitrification and denitrification release another greenhouse gas, nitrous oxide. Apart from these significant risks and the production of greenhouse gases, the mismanagement of cow dung also causes air, water, and soil pollution. So, its proper management is of utmost importance. Various management strategies have been adopted to convert cow dung into a valuable bioresource that is beneficial to the environment. These strategies include anaerobic digestion, composting, biochar production, and integrated manure management. Such approaches not only lead to the production of useful eco-products like biogas and biofertilizers but also help in improving soil fertility. These practices provide job opportunities through the establishment of biogas plants and composting units, thus supporting sustainable and rural development. Further, the dependence on fossil fuels in rural areas is greatly reduced. So, the use of cow dung in the future focuses on minimum environmental and health risks, proper manure handling, and greater biogas production. With new and advanced technologies, reduction in greenhouse gas emissions will be achieved. Strong government support and active involvement of rural communities are essential. All these changes can transform cow dung into a potent resource for climate-smart agriculture, clean energy production, and sustainable circular economy practices.

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How to Cite This Article
Goyal R, Vaish M, Verma S. Cow dung-precursor for climate change a review. International Journal of Veterinary Sciences and Animal Husbandry 2025; SP-10(10): 154-161.