

# Reducing Methane Emissions in Ruminant Production: Methods and Their Impacts

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**Abstract.** Introduction: Greenhouse gases contribute significantly to the greenhouse effect, with methane being one of the primary gases. Methane emissions largely stem from ruminant production. Reducing methane emissions from ruminants is beneficial for the environment and improves the feed efficiency of the animals. This article examines the process by which cattle produce methane in the rumen through enteric fermentation and how this methane is subsequently released into the atmosphere. Additionally, various methods to mitigate methane emissions from ruminants are summarized. Main text and discussion: Several methods to address methane emissions from cattle were discussed. First, feed additives: Adding certain compounds or biological extracts to cattle feed can significantly reduce methane emissions. Second, efficient feeding management: Intensive management strategies, such as feeding cattle at specific times, can minimize energy loss and improve feed efficiency. Third, genetic methods: Genomic selection can be used to select animals with lower methane emissions, and gene editing tools can be employed to modify the genes of cattle. Breeding varieties that produce less methane, such as miniature cows, were also considered. The advantages and disadvantages of each biological solution were summarized. Furthermore, political and economic strategies that could potentially replace conventional beef were explored. Conclusion: The greenhouse effect caused by greenhouse gases presents a major challenge that requires a multifaceted approach. Genetic engineering, including gene editing, shows promise but is still developing. Feed additives can reduce ruminant methane emissions, while legislative measures can improve economic structures. Cultured or alternative meats can serve as substitutes for ruminant meat. Although each method has limitations, combining them may yield the best results.

## 1 Introduction

The rapid increase in greenhouse gases exacerbates the greenhouse effect, leading to numerous problems, including extreme weather and natural disasters. Human-induced warming primarily intensifies arid climates and reduces polar climates, causing low-latitude climates to shift to higher latitudes and low-altitude climates to higher altitudes. This alters local environments and exceeds the tolerance limits of local ecosystems. For example, rising temperatures in high-latitude areas accelerate permafrost melting, resulting in abiotic and biotic disasters, such as wildfires and insect infestations, which threaten northern forests. Climate change also increases land desertification and drought frequency, reducing soil water availability for plant growth and potentially converting some temperate drylands into subtropical drylands. Regions with higher greenhouse gas emissions will experience a faster rate of warming than the global average <sup>[1]</sup>. Many landmasses are likely to have an increase in hot days, and anthropogenic greenhouse gas emissions have intensified and increased the frequency of heat-related events since around 1850, with the global average surface temperature rising by approximately 0.87 degrees Celsius by 2015.

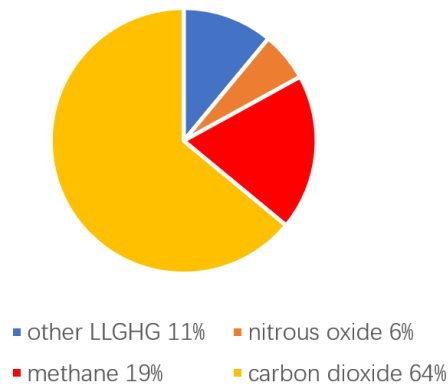
The increase in greenhouse gases can lead to various social and economic problems. For example, rising temperatures can reduce crop yields, such as wheat yields decreasing by 4-6% for every degree of temperature increase. Longer frost-free periods due to increased greenhouse gases can cause vegetation to grow and bloom earlier, only to be frostbitten by late spring frosts <sup>[2]</sup>. Extreme temperatures and precipitation have contributed to an 18-43% decline in the yields of maize, soybean, rice, and spring wheat <sup>[3]</sup>. Reduced food production can result in widespread hunger. Additionally, extreme temperatures can disrupt the normal physiological functions of many trees, reducing photosynthesis and increasing leaf shedding, potentially leading to extensive forest die-offs <sup>[4]</sup>.

Greenhouse gases include carbon dioxide, methane, nitrous oxide, hydrochlorofluorocarbons, and hydrofluorocarbons. Their contributions to the increase in global radiative forcing from the pre-industrial era to 2022 are shown in Fig. 1. Carbon dioxide, methane, and nitrous oxide are the most impactful and longest-lived greenhouse gases, contributing 64%, 19%, and 6% respectively. Greenhouse gases originate from various sources, with Agriculture, Forestry, and Other Land Use (AFOLU) being significant contributors. Between 2007

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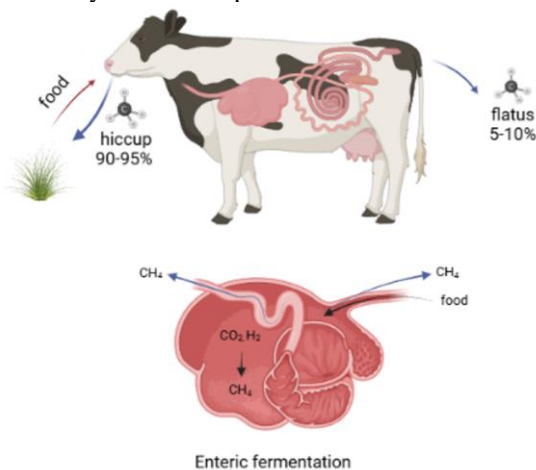
and 2016, carbon dioxide, methane, and nitrous oxide from AFOLU accounted for about 23% of the total. Methane, about 20 times more potent than carbon dioxide in trapping heat in the atmosphere, is a significant greenhouse gas. One often overlooked source of methane emissions is ruminant farming, which plays a crucial role in the accumulation of methane in the atmosphere.

Contribution of the most important LLGHG to the increase in global radiative forcing from the pre-industrial era to 2022

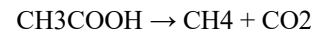
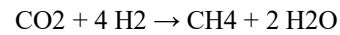


**Fig. 1.** The contribution of major LLGHGs to the increase in global radiative forcing.

The rumen is a specialized physiological organ in ruminants, functioning as the first stomach where food enters during digestion. It has the unique capability of digesting fiber-rich foods. Methane production in ruminants primarily occurs through fermentation in the rumen and is released into the air via burping, with a smaller portion produced in the large intestine and expelled as flatulence (Fig. 2). The rumen hosts a vast array of microorganisms, including anaerobic organisms such as methanogens, which facilitate methanogenesis. The primary reactants in the methane production process are carbon dioxide, hydrogen, and acetic acid, as illustrated in the chemical equations below. Notably, in the rumen, most of the acetate is typically absorbed into the bloodstream, with hydrogen contributing more significantly to methane production [5].



**Fig. 2.** The process of methane production in the rumen of cattle.



Methane production in the rumen is a natural physiological phenomenon. However, studies have shown that methane emissions vary among different animals. Furthermore, methane production is closely linked to the animal's feed efficiency, as methane represents an energy loss for ruminants, accounting for 2%-12% of their total energy intake [6]. Reducing methane production can therefore improve the feed efficiency and overall production efficiency of the animals. This article focuses on strategies to reduce methane emissions through the manipulation of rumen flora, digestion optimization, and genetic selection.

## 2 Main text

At present, various studies and solutions are being explored to reduce methane emissions from ruminant farming (Table 1). One promising method is microbial engineering to alter the microbiota in the rumen. By modifying the microbial community, we can reduce the emission of various greenhouse gases. For example, adding specific compounds like bromoform from *Asparagopsis taxiformis* to cattle feed can significantly reduce methane emissions. Some of these methods are already in use, but others require further evaluation for safety, efficacy, and other potential issues. Additionally, leveraging the special abilities of certain organisms to reverse methane production holds promise. For instance, organisms capable of anaerobic oxidation of methane, found in some marine and freshwater environments, can use nickel-containing proteins similar to methyl-coenzyme M reductase to reverse methanogenesis [7]. In the cow's rumen, sulfate ions react with methane under anaerobic conditions to produce bicarbonate ions, hydrogen sulfide ions, and water, a process catalyzed by sulfate-reducing bacteria [8]. The reaction equation can be written as  $\text{SO}_4^{2-} + \text{CH}_4 \rightarrow \text{HCO}_3^- + \text{HS}^- + \text{H}_2\text{O}$  [9].

Adding various ingredients to cattle feed can effectively reduce methane emissions and improve feed efficiency. Increasing the fat content of feed reduces fiber fermentation and inhibits methanogenic bacteria activity [10]. Using easily digestible feed or adding ingredients that support digestion can improve energy conversion efficiency, thereby reducing methane production and increasing beef yield [11]. Additionally, adding methanogenesis inhibitors such as 3-nitrooxypropanol (3-NOP) can inhibit the final step of methane synthesis by rumen microorganisms [12]. However, some inhibitors may be harmful or interfere with the normal physiological activities of cattle, leading to reduced productivity. Commercial feed additives like prebiotics and enzymes can improve digestibility, although they may increase production costs [13]. Plant secondary metabolites, such as lycopene and clove oil, also show potential in inhibiting rumen methane production. For example, feeding cattle with small amounts of *Asparagopsis taxiformis* has been proven to significantly reduce methane emissions, though this method can be costly or have other adverse effects [11].

In addition to feed modification, implementing refined breeding management practices can enhance feed utilization and reduce methane emissions. Precision feeding techniques, which involve providing the exact amount of feed at the right time, can improve feed efficiency and animal health [14]. Genetic selection is another promising strategy, where animals with naturally lower methane emissions are selectively bred to reduce overall herd emissions [15]. This method can be integrated with genomic technologies to identify and select desirable traits more accurately. Furthermore, integrating pasture management strategies, such as rotational grazing, can improve forage quality and soil health, contributing to reduced methane emissions [16]. Optimizing the grazing system ensures that animals have access to high-quality feed, enhancing digestion and reducing methane production [11]. Continuous research and development in these areas are crucial to finding cost-effective and practical solutions for the livestock industry.

With the help of genetic technology, we can alter the microbiota in the rumen by changing the genes that control it. The rumen microbiota of cattle varies at both the individual and species levels. For example, if individual A produces less methane than individual B, we can identify the genetic differences between them and use gene editing tools to modify individual B's genes to match those of individual A, thereby reducing methane production [15]. At the species level, miniature cattle offer a unique advantage. These cattle, which are smaller than traditional cattle, consume less feed and produce less methane. On the same plot of land, farming miniature cattle can yield more meat and require fewer resources, providing economic benefits. However, miniature cattle often face issues such as high rates of malformation in offspring. Gene editing tools can partially modify their genes to reduce undesirable traits, but genetic engineering has limitations. Unrestrained genetic modification can have unpredictable consequences [14]. Ethically, it is inhumane to experiment on sentient animals without considering their well-being, making animal experiments time-consuming and complex.

Gene editing technologies such as CRISPR-Cas9 offer significant potential to reduce methane emissions from cattle. These technologies can make precise changes to the cattle genome, such as tweaking the gastrointestinal microbiome to reduce methane-producing bacteria [17]. It is also possible to directly modify cattle genes to alter their digestion process, reducing methane production [11]. Genetically modified organisms can introduce specific genes that produce methane-resistant compounds or enhance digestion efficiency, further reducing methane production. Optimizing the bovine microbiome through the addition of beneficial microorganisms or genetic engineering of existing ones can also reduce methane emissions [16].

**Table 1.** Summary of methods described in the main body for reducing methane emissions from ruminant farming.

Methods	Positive Points	Negative Points
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Microbial Engineering	Significantly reduces greenhouse gases	Safety and efficacy still under evaluation
Adding Red Seaweed and Other Additives	Reduces methane emissions, improves feed efficiency	High cost, potential side effects
Increasing Feed Fat Content	Inhibits methanogenic bacteria, reduces fiber fermentation	Affects diet balance, potential health issues
Easier Digestible Feed	Improves energy conversion efficiency, reduces methane	More expensive, requires nutritional balance
Methanogenesis Inhibitors (e.g., 3-NOP)	Effectively inhibits methane synthesis	May be harmful, affects normal physiology
Commercial Feed Additives (e.g., prebiotics, enzymes)	Improves feed digestibility, enhances health and productivity	Increases production costs, long-term effects need study
Plant Secondary Metabolites (e.g., lycopene, clove oil)	Natural inhibition of methane production	Efficacy and cost-effectiveness need further research
Precision Feeding Techniques	Improves feed efficiency, enhances health	Requires technology investment, complex implementation
Genetic Selection	Reduces overall herd emissions, high accuracy	Long-term process, requires extensive research and data
Gene editing	Direct change genome	Technical difficulties, ethical issues

### 3 Discussion

Various strategies to mitigate methane emissions from ruminant farming have been discussed in the main text. This section focuses on the potential of red seaweed as a feed additive, the production of miniature cattle, and the role of government policies in reducing methane emissions.

Red seaweed, particularly the species *Asparagopsis taxiformis*, can be used as a feed additive for cattle to reduce methane emissions due to its high content of bromoform (CHBr<sub>3</sub>), a compound that inhibits the enzyme responsible for methane production in the digestive system of ruminants. When cattle consume red seaweed, the bromoform interferes with the methanogenesis process in the rumen, leading to a significant reduction in methane production. It has been shown that red seaweed is highly effective as a feed

additive for reducing methane emissions, although its efficacy varies across different studies. Additionally, it has been observed that cattle fed with red seaweed maintain or even improve their overall health and productivity, as energy that would have been lost as methane can be redirected towards growth. However, there are drawbacks to consider, such as the high cost for transporting wet seaweed and the limited availability of red seaweed. Potential impacts on the taste and quality of the meat or milk, as well as the need for a consistent supply and incorporation into cattle diets, are also concerns. Ensuring sustainable harvesting and production of red seaweed is crucial to avoid negative ecological impacts on marine environments.

The concept of replacing traditional cattle with miniature cattle (mini cattle) presents a compelling approach to addressing several agricultural and environmental challenges. This discussion examines the feasibility and challenges associated with such a shift, considering factors such as economic viability, environmental impact, market acceptance, and genetic diversity. One of the primary advantages of mini cattle is their reduced feed requirements. Mini cattle consume approximately 30% to 50% less feed than traditional cattle, which can significantly lower feed costs for farmers<sup>[18,19]</sup>. Additionally, mini cattle require less land and water, making them a cost-effective option for smaller farms or regions with limited agricultural resources<sup>[20]</sup>. However, the economic feasibility also depends on market demand. Mini cattle produce less meat per animal, which could affect profitability unless market preferences shift toward higher-priced, specialty meats known for quality rather than quantity<sup>[21]</sup>.

The environmental benefits of mini cattle are noteworthy. Their smaller size results in lower methane emissions, a major concern in global greenhouse gas emissions<sup>[22]</sup>. By reducing methane output, mini cattle can contribute to more sustainable livestock farming practices. Moreover, their lower resource requirements align with sustainable agriculture principles, reducing the strain on land and water resources<sup>[23]</sup>. Market acceptance remains a critical hurdle. Traditional beef markets are well-established, with consumer preferences and supply chains built around larger cattle breeds<sup>[24]</sup>. Introducing mini cattle on a large scale would require significant shifts in consumer behavior and market infrastructure. Education and marketing efforts highlighting the environmental benefits and unique qualities of mini cattle meat could foster acceptance<sup>[25]</sup>. Furthermore, partnerships with chefs and restaurants focusing on sustainable and high-quality meat could help build demand<sup>[26]</sup>.

One of the significant challenges in the widespread adoption of mini cattle is their genetic diversity. Mini cattle often suffer from a limited gene pool due to selective breeding practices aimed at maintaining their small size<sup>[26]</sup>. This reduced genetic diversity can lead to increased susceptibility to diseases and lower overall resilience<sup>[27]</sup>. Strategies to mitigate these issues include crossbreeding with genetically diverse breeds and employing modern genetic screening and editing techniques to enhance health and resilience<sup>[28]</sup>. Managing

mini cattle involves unique considerations. Their smaller size makes them easier to handle and reduces the risk of injury to farm workers, which can be particularly beneficial in small-scale or family-run farms<sup>[18]</sup>. However, addressing the genetic diversity issue is critical. Efforts to improve genetic diversity can involve introducing new genetic material through careful crossbreeding programs and using genomic technologies to identify and propagate beneficial traits<sup>[29]</sup>.

Replacing traditional cattle with miniature cattle on a large scale offers several potential benefits, including lower feed costs, reduced environmental impact, and easier management. However, challenges such as market acceptance and genetic diversity need to be addressed. With strategic efforts in breeding, market education, and environmental advocacy, miniature cattle could become a viable alternative to traditional cattle, contributing to more sustainable and efficient livestock farming practices.

Exploring alternative protein sources is crucial, and one such source is artificial meat, also known as cultured meat or lab-grown meat, which is produced by cultivating animal cells in a controlled environment, bypassing the need to raise and slaughter livestock. The current production costs of cultured meat are still high, but future technological advancements could reduce these costs, gradually making cultured meat affordable for the public<sup>[30]</sup>. Alternatively, meat production could be replaced with other, more environmentally friendly animals. Efforts could be made to process the taste and texture of these alternative meats to resemble that of cattle. However, this shift may require significant psychological adjustment and acceptance from the public<sup>[31]</sup>.

From a public policy perspective, several strategies could efficiently reduce methane emissions from ruminants. One approach the government can take is to impose a fee on the daily amount of greenhouse gases produced by individuals, essentially a tax. This policy will be implemented in places such as New Zealand in 2025. Implementing such government policies and taxes on greenhouse gas emissions, while potentially effective, necessitates extensive political discussion and consensus-building. Democratic processes require that such policies gain public approval, which often involves prolonged debate and negotiation<sup>[13]</sup>. Another approach involves consolidating small family farms into larger, more intensive ruminant production operations. This strategy aims to avoid the waste of energy and large emissions of greenhouse gases caused by poor feeding practices on small farms. However, these and other policies also require the consent and vote of many people, leading to lengthy political discussions<sup>[32]</sup>. Consolidating small farms into larger operations may indeed improve efficiency and reduce emissions, but this approach must carefully balance the economic impacts on small farmers with the environmental benefits. Overall, while government strategies such as greenhouse gas taxes and the consolidation of farms hold promise, they require careful consideration of economic impacts, technological feasibility, and public acceptance. Investing in research and development, alongside public education and collaborative policy-making, can help create sustainable

solutions to reduce greenhouse gas emissions and promote environmentally friendly food production<sup>[33]</sup>.

## 4 Conclusion

The greenhouse effect caused by greenhouse gases is a significant challenge facing human society today, and addressing this issue through genetic engineering, such as gene editing, is both necessary and urgent. However, progress in this field is still developing. To mitigate the problem, we must consider a multifaceted approach. For example, feed additives could efficiently reduce ruminant methane emissions by suppressing certain microbes and related reactions in generating methane in the rumen. Additionally, improving economic structures through legislative measures and utilizing cultured meat or meat from other animals to simulate ruminant meat are also potential strategies. Each of these methods has its own limitations, but by combining them, we may achieve the best possible results.

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