# The Methane Paradox: Cattle, Climate Change, and Environmental Challenges

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## INTRODUCTION

In this ever-evolving world struggling with environmental challenges, the impact of anthropogenic activities threatens the delicate balance of our planet's existence. Among the myriad concerns, releasing methane gas from cattle has risen as a pressing global issue. Methane ($CH_4$) is a powerful greenhouse gas that is able to trap heat in the Earth's atmosphere 25 times more effectively than carbon dioxide. Methane release into the atmosphere contributes to the intensification of the greenhouse effect, accelerating global warming and climate instability (Crutzen et al., 1986).

The unique digestive system of ruminant animals, such as cattle, facilitates microbial fermentation in the rumen, resulting in the production and release of methane gas into the atmosphere (Króliczewska et al., 2023). The cattle industry is the major contributor to methane release which comes from the ubiquitous and vital aspect of human existence. Livestock, particularly cattle, are an essential part of agricultural practices, providing dairy, meat, leather, and other valuable products (Danielsson et al., 2017). Nevertheless, the scale of cattle farming in recent decades has grown globally with the increase in demand for food. This led to the concerning issue of escalating methane emissions from animals and related ecological impacts (Johnson & Johnson, 1995).

This review article delves deep into the issue of methane release from cattle, exploring its causes, impact on the environment, and potential strategies to mitigate this pressing challenge. By incorporating existing research and employing expert insights, we aim to elucidate the importance of the issue and encourage contributors from diverse sectors to join hands in crafting sustainable solutions. In the subsequent sections, the biological mechanisms behind methane production in cattle, factors that influence methane production in cattle, statistics on global methane emissions, environmental impacts, policy and regulation, and mitigation strategies were discussed.

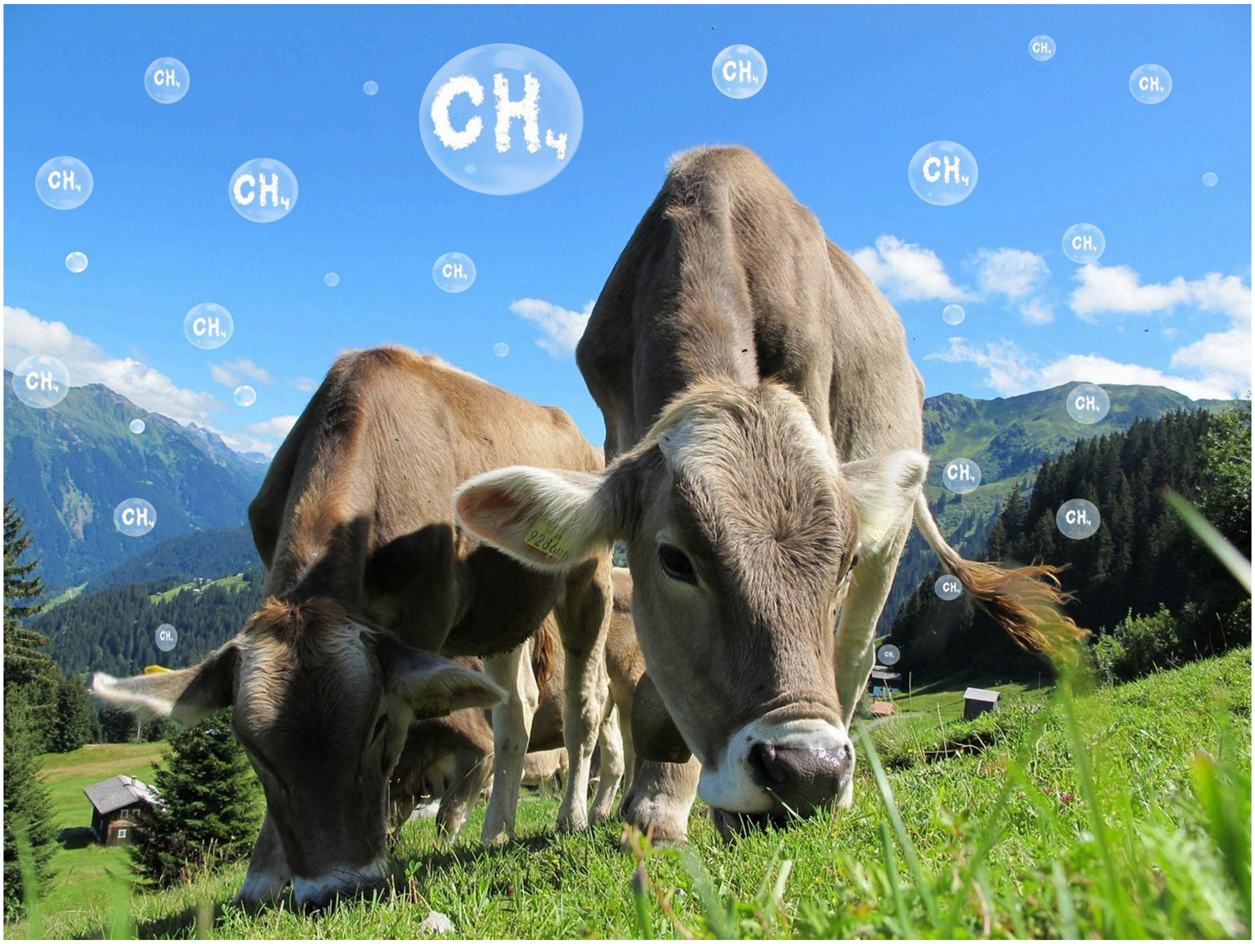

Figure 1: Cattle industry is the major contributor to global methane release.

## Methane Production in Cattle

Enteric fermentation refers to the process that takes place in the gastrointestinal tract of ruminant animals including goats, sheep, and cows. It involves the breakdown of complex carbohydrates into simple molecules by microorganisms present in the rumen (the first compartment of the stomach) of these animals. This mechanism produces volatile fatty acids (VFA) and gases, including Hydrogen (H), Carbon dioxide ($CO_2$), and methane ($CH_4$) (Russell, 2009).

As ruminants consume plants, they undergo a series of biochemical reactions in the digestive system. Fermentation of food is orchestrated by the rumen microbiome resulting in the production of a variety of VFAs, such as butyric acid, propionic acid, acetic acid, and other end products (Borja & Rincón, 2017). However, the most significant byproduct of enteric fermentation is methane ($CH_4$), which is released into the digestive system and ultimately expelled by the animal through belching.

Methanogens utilize $H_2$ generated during fermentation for the reduction of $CO_2$ to methane ($CH_4$) and water through a process known as methanogenesis (Buan, 2018). This process occurs in an environment devoid of oxygen, such as the anaerobic conditions present in the rumen. The overall reaction can be summarized as :

$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

Methanogens are unique in their ability to carry out this biochemical conversion. The amount of methane produced depends on various factors.

## FACTORS THAT INFLUENCE METHANE PRODUCTION IN CATTLE

Production of methane in ruminants is a complex process influenced by various factors, including diet, breed, management practices, microbial population, and rumen conditions.

**1. Diet:** The diet of ruminant animals plays a significant role in methane production, which contributes to greenhouse gas emissions. Ruminants possess a unique digestive system capable of fermenting fibrous plant materials, but this process also generates methane. Diets rich in highly

fermentable carbohydrates, such as grains and concentrates, tend to contribute to higher methane emissions compared to diets based on fibrous forages like grass and hay.
The breakdown of complex carbohydrates in the rumen produces fermentable substrates that serve as a food source for methanogenic microorganisms, leading to increased methane production (Broucek, 2014).

**2. Breed:** Cattle breeds exhibit distinct levels of methane production due to variations in their digestive systems and metabolic rates. Some breeds have been observed to produce less methane compared to others. For example, Bos indicus breeds, such as Zebu cattle, have been observed to exhibit lower methane emissions compared to Bos taurus breeds, such as Holsteins or Jerseys (Danielsson et al., 2017). This difference is attributed to variations in rumen microbial populations, rumen pH, efficiency of feed digestion, and utilization among different breeds.

**3. Age and physiological factors:** Methane emissions can also be influenced by the animal's physiological state and age. Young animals tend to have higher methane production rates compared to mature ones. As animals age, their rumen microbial populations become more established and efficient, resulting in reduced methane emissions. Additionally, physiological factors such as pregnancy and lactation can affect methane production due to changes in feed intake, nutrient requirements, and rumen function (Grandl et al., 2016).

**4. Feeding management practices:** Factors such as feed processing, feeding frequency, and feeding systems can influence methane production in ruminant animals. Infrequent
feeding results in greater methane emissions compared to frequent feeding. Ionophores or specific types of oils, can help reduce methane emissions by modulating rumen fermentation and microbial activity (Vargas et al., 2022).

**5. Animal health and genetics:** The health of cattle, including their gut health and overall microbial balance, can affect methane production. Due to health issues, imbalances, or disruptions in the rumen, the microbial community can alter fermentation patterns and increase methane production. Genetic factors also possess a significant role in methane emissions. Recent studies report that certain genetic markers are associated with lower methane emissions in cattle, indicating the importance of selecting animals with less methane production through breeding programs (Lassen & Difford, 2020).

**6. Environmental conditions:** Environmental factors influence methane production in ruminants. Temperature and humidity levels can affect the population of gut (rumen) microorganisms and their activity. For example, Heat stress can increase respiration rates and reduce feed intake, which may indirectly affect methane emissions. Additionally, changes in forage quality and availability due to climate changes can impact methane production (SHIBATA & TERADA, 2010).

## STATISTICS ON GLOBAL METHANE EMISSIONS

According to the Food and Agriculture Organization of the United Nations (FAO), the livestock sector is a significant contributor to methane emissions at the global level. The FAO estimates that approximately 14.5% of total man-made methane release are from the global ranching and farming industry. This includes emissions from organic waste handling and manure management. The gastrointestinal digestion, rice cultivation, and animal waste play important roles in CH4 emission, collectively contributing about 40% of CH4 release from the agriculture sector.

Cattle hold a major share in contributing to methane emissions. The FAO estimates that cattle (both beef and dairy) are responsible for approximately 65% of total methane ejections. The methane release from cattle vary across regions due to differences in livestock management, feeding practices, and breed characteristics. Regions with significant cattle populations, such as

South America, Africa, and Asia, tend to have higher methane emissions from cattle (Food and Agriculture Organization of the United Nations, 2021).

## ENVIRONMENTAL IMPACTS

The ecological impacts of methane release from livestock are significant and contribute to various environmental challenges. Some of the key environmental impacts are

**1. Greenhouse gas emissions:** Methane gas contributes remarkably to the production of ground-level ozone. Each year, this pollution causes over 1 million premature deaths. Methane also has a considerable greenhouse effect since it is about 80 times more powerful than CO2 in heating the Earth. It contributes to global warming and climate change by trapping heat in the atmosphere. Both natural and anthropogenic sources generate methane, such as wetlands, livestock production, fossil fuel extraction, and waste decomposition (McArthur, 2021). Methane's impact on global warming occurs over a shorter timescale, and its release can create positive feedback loops that amplify its emissions.

**2. Air Quality:** Methane is not directly harmful to human health, it lead to the production of a harmful air pollutant, ground-level ozone. Ground-level ozone cause respiratory issues, worsen lung conditions, and negatively affect the air quality in urban and agricultural areas (Staniaszek et al., 2022).

**3. Habitat Destruction:** In Addition, methane emissions from cattle have the potential to disrupt biodiversity and ecosystems. As a greenhouse gas, methane has a role in regulating climate change, which in turn affects habitats, species distribution, and the health of ecosystems as a whole. The delicate balance of ecosystems may tend to fluctuate with temperature changes and precipitation patterns. This can change plant features, alter migratory patterns, and increase the probability of extinction for some species. Increasing methane levels in the atmosphere can cause changes in temperature levels, sea levels, and ecosystems (Staniaszek et al., 2022).

## MITIGATION STRATEGIES

Methane has a shorter atmospheric lifetime with a half-life of 8.6 years, compared to CO2. This feature makes it an attractive focus for short-term global warming mitigation efforts. Reduced CH4 emissions are of paramount importance in this scenario of amplifying global temperature (Muller & Muller, 2017)). As a result of understanding the mechanism behind methanogenesis, identifying and executing efficient techniques to regulate the same are also evolving. Since early 2000, enteric CH4 emissions have received traction from the research communities and several strategies have been implemented for the mitigation of the CH4 emission. Nevertheless, these strategies were influenced by higher costs, affects animal and human health, as well as environmental factors. Some of the approaches, potential benefits, challenges, pros, and cons are,

### Dietary Modifications

Dietary modifications provide the most simple and low-cost approach to lower enteric CH4 emissions by up to 70% depending upon various factors. One way to modify the diet is by changing the quality of forage (by changing the forage type) or changing the forage-concentrate ratio. An example of high-quality forage will be young tender plants that have a lower Carbon-Nitrogen ratio, less non-digestible fiber, and higher fermentable carbohydrates (Hills et al., 2015).

Features like this of high-quality forage will make sure of better digestibility and decrease methane production by increasing propionate production. Propionate acts as a competitor with methane (CH4) as a hydrogen (H) sink, resulting in leaving less hydrogen for the process of methanogenesis (Beauchemin, 2009). As productivity is a major concern regarding the ruminant animals and diet is directly correlated to productivity, forage alone may not be able to produce the desired performance; hence concentrates (readily fermentable sugar and starch) are provided. A higher proportion of concentrates in the feed may lead the mammals to health issues, but 40% - 60% of concentrate was observed to be increasing productivity (McGuffey et al., 2001). In addition, it aids in curtailing methane production. Substituting maize silage instead of grass silage is likely to reduce methane emissions by promoting propionate production than acetate. The Dry Matter Intake (DMI) will reduce ruminal fermentation and promote post-ruminal digestion (Ranga Niroshan Appuhamy et al., 2013).

## Feed Additives

### Saponins

Saponins are surface active glycosides comprised of glycon-saccharide and aglycone-sapogenin. The primary producers are bacteria, lower marine animals, and plants. In the case of ruminant diets the sources are Quillaja saponaria, Yucca schidigera, Medicago sativa, and Camellia sinensis (Jayanegara et al., 2014) .

Saponins were reported for exhibiting the capability to reduce methane emissions. Defaunation refers to the extinction of animal populations or species at either a global, local, or functional level within ecological communities. This mechanism aids saponins in the reduction of CH4 emissions. The ciliate protozoa perform a significant function in ruminal protein recycling and protein passage to the duodenum. Characteristic conformation of saponins helps in forming compounds with sterols in protozoan cell membranes in the rumen disintegrating the protozoan cell (Patra & Saxena, 2009). This will negatively affect the CH4 emission. The antiprotozoal property will only impart a temporary effect on microorganisms as they can convert saponins into sapogenin through the process of deglycosylation (Wina et al., 2005).

Even though saponins have been reported to affect methane production, all the saponins cannot be considered edible. High doses of saponins may act as toxic, hence the structure, dosage, source, species of origin, and diet are complementary factors that should be taken into account (Moses et al., 2014). Saponin toxicity may vary from plant to plant and differ in their habitat. In most of the plant species saponin synthesis is driven by abiotic and biotic stress like light, temperature, pathogen attacks, nutrient starvation, and humidity. To avoid such danger factors, proper monitoring and processing of food for saponin concentration reduction (chemical treatment, heat treatment, or other methods to remove or break down saponins) are advised. In conditions like unavoidable high-level saponin exposure, monitoring animals closely for toxicity-related signs and providing veterinary care are recommended (Samtiya et al., 2020).

### Tannins

Tannins are potential secondary polyphenolic metabolites that can have an impact on the rumen environment and are associated with the plant's defense mechanism against herbivores, pathogens, and UV radiation. Condensed tannins, a classification of tannins, were reported to have anti-methanogenic properties as they have the potential to influence the digestibility of feed and modify rumen fermentation, thereby reducing methane emissions (Liu et al., 2011).

These metabolites can interfere with $CH_4$ emission by engaging directly with methanogens and indirectly by influencing the $H_2$-producing microflora. The affinity of tannins towards the proteins by the interaction between phenolic hydroxyl groups of tannins with amino acid residues of proteins constitutes the anti-methanogenic activity of tannins (Vasta et al., 2019). These interactions can modify the conformation as well as the function of the protein. A direct positive correlation between ciliate protozoa (having a relation with methane-producing archaea) and methane emissions were reported. The condensed tannins have a toxic effect on the ciliate protozoa, supported by studies stating the reduction of the protozoa population in sheep taking a condensed tannin-rich diet (Field et al., 1989).

On the other hand, high concentrations of tannins may affect the digestive health of ruminant animals. Limiting the availability of nutrients for uptake negatively impacts productivity and growth. Similarly, these polyphenols can interact with essential minerals and limit them from being available for absorption. In addition, gastrointestinal imbalances can also be an outcome of high-concentration intake. Some tannins, especially when present in large quantities, might have negative effects on animal health. They can cause gastrointestinal disturbances or limit the intake of feed due to their bitter and astringent taste (Smith et al., 2005). Additionally, certain tannins can bind with essential minerals, leading to reduced mineral absorption in the animal's body.

### Ionophores

Carboxylic polyether chemical species from Streptomyces spp. that can bind and transport ions across cell membranes are termed Ionophores. Lasalocid, salinomycin, monensin, narasin, and laidlomycin are some of the commercially available ionophores. These chemical species are the approved feed additives focused on increasing body weight and feeding efficiency of animals by regulating fermentation patterns and enhancing ruminal nitrogen metabolism (Russell & Strobel, 1989). Moreover, they can interfere indirectly with methanogenesis by inhibiting the production of hydrogen-producing gram-positive bacteria which will cut off the hydrogen supply for methanogens. And also, the Ionophores are negatively correlated with ciliate protozoa which in turn affect methane emission negatively. Nevertheless, ionophores have some disadvantages like impairing dry matter intake in ruminants. Ciliate protozoa adapt against the suppressing effect of ionophores (Marques & Cooke, 2021).

## Methanogenesis inhibitors

A class of chemicals functioning as inhibitors of methane production can be termed methanogenesis inhibitors. Based on the inhibition of the targets, the inhibitors were classified into specific and non-specific inhibitors. The former targets methanogens while the latter targets both methanogens as well as non-methanogens (Liu et al., 2010). Focusing on the methanogenesis inhibitors, the methyl Coenzyme M reductase is an attractive target for long as it catalyzes a crucial step in methane production, which involves a methyl transfer from coenzyme M. As a result, methane is released from methyl coenzyme M as the protein gets reduced (Shima et al., 2012).

3-Nitrooxypropanol, a structural analog of Coenzyme M is binding with methyl-coenzyme M reductase competitively and interacts with the protein, In the process, 3-Nitrooxypropanol inhibits and inactivates the protein. As the toxins from 3-Nitrooxypropanol are tolerable by the microbes, the microflora are not negatively affected along with a noticeable reduction in the methane emission ranging from 20% - 55%. Chloroform, a halogenated aliphatic hydrocarbon, is reported for its potential for the inhibition of corrinoid enzymes and methyl-coenzyme M reductase. This compound inhibits both hydrogenotrophic ($H2/CO2 \rightarrow CH4$) and acetoclastic ($CH3COOH \rightarrow CH4$) methanogens. Long-chain fatty acids are known for the disruption of gram-positive bacterial cell membranes (Zhang et al., 2018).

## Flavonoids

Flavonoids are a class of polyphenolic secondary plant metabolites with 2 benzene rings and have structural similarities with tannins. These compounds possess antimicrobial properties. Flavonoids inhibit methanogenesis by absorbing the hydrogen from the cleavage of the carbon ring which leads to the deficit of Hydrogen for CH4 production (Islam & Lee, 2019). Besides, they elevate the propionate level compared to the acetate level. As a result, the productivity of ruminants can also be elevated. Naringine, Neoeriocitrine, Hesperidine, Isonaringine, and quercetin are some of the flavonoids used commercially. They decrease methanogenesis by 4 - 10% and increase propionate concentration. Commercially available feed additives were reported to have a significant difference in the yields produced by different high-cost conventional methods (Chen et al., 2019).

### Microbiome manipulation

Microbiome Manipulation is one of the strategies to mitigate CH4 emissions from ruminant animals. The rumen microbiome/microflora consists of diverse microorganisms, including bacteria, archaea, fungi, and protozoa. Specific species of microbes are responsible for the production of methane during metabolism. Manipulation of these microbiome species in the rumen, to reduce methane emissions is under research for a long time. By understanding the intricate interactions between different microbial species and their functional roles, it is possible to develop targeted approaches that can decrease methane production without compromising the efficiency of digestion and nutrient utilization (Yáñez-Ruiz et al., 2015). Defaunation of rumen and probiotics are some of the strategies by which the microbiome can be manipulated for lowering CH4 emissions.

### Defaunation of rumen

In general, defaunation refers to the reduction, decline, or extinction of a particular population on a global/ geographical scale. Here, rumen defaunation refers to the reduction/ elimination of the rumen protozoa population. In chemical defaunation, antimicrobial substances, such as antibiotics or chemical agents like formaldehyde were used to selectively kill the rumen microorganisms while in physical defaunation, applications such as centrifugation or heat treatment were used to disrupt and separate the microbial populations (Santra & Jakhmola, 1998).

The process is generally related to enhanced animal productivity and increased microbial protein supply.

The ciliate protozoa are considered as an important formate and H2 producer, and they tend to get attached to methanogens on the cell surface which favors the Hydrogen transfer. These methanogens with protozoa were reported for 10- 30% of methane production. In summary, the ciliate protozoa facilitate the supply of substrates for CH4 production as well as protect archaea from ROS attacks (Guyader et al., 2014).

A linear correlation has been reported between rumen protozoa concentration and methane production by methanogens. Increased propionate concentration, decreased butyrate levels and methane production are the aftermath of the defaunated rumen. On the other hand, the process will have a positive impact on the protein-synthesizing efficiency of bacteria, the density of the bacterial population, reduced carbohydrate digestion, and regulation of nitrogen flow to the duodenum (Newbold et al., 2015). Recently, secondary metabolites from plants were reported to be aiding in defaunation. Partial defaunation was not found to be effective in decreasing CH4 emissions while whole defaunation was found to rescue the same by 20% in 2 years.

Defaunation exhibits the capability of being a potential mitigation technique, but permanent methods of defaunation are difficult due to contamination caused by animal crossing. Decreased food intake, organic matter digestibility, and long-term consequences like toxicity on microfloral and animal health will also undermine the cause to consider defaunation as a methane mitigation strategy.

## Probiotics

Probiotics are the selected cultures of yeast or bacteria that regulate the gastrointestinal microflora to improve animal health. An established relationship is reported between methane production and propionate, acetate, and nitrate level. These molecules act as an alternative Hydrogen sink which in turn reduces CH4 emissions or the key substrate to reduce methane generation (Tavendale et al., 2005).

In the rumen, the formation of CH4 using CO2 is less favorable (thermodynamically) than the reduction of NO3- and NO2- to NH3 by using Hydrogen. Probiotic bacteria possess the ability to reduce NO3-, NO2-, and SO42-, thus competing with CH4 for Hydrogen (Latham et al., 2016). Sulfate-reducing bacteria yield is influenced by the amount of SO42- provided in the diet. In addition, probiotics may stimulate acetogenic bacteria that also compete with methanogens for Hydrogen. Current research and applications have concentrated on three main categories of probiotic bacteria - Propionibacteria, homoacetogens, and nitrate/nitrite-reducing bacteria.

Propionibacteria (species like Propionibacterium acidipropionici, P. freudenreichii, P. propionicus, P. jensenii, P. japonicas, P. japonicas, and P. thoenii.) a gram-positive bacteria naturally constitute a small percentage of the overall microbial population at around 4.3%. These species play a crucial role in producing propionate by using H2, which is also required for methane production. Several strains of Propionibacteria have undergone testing in both controlled environments and live animal studies (Counotte et al., 1981). Some strains have demonstrated a remarkable ability to reduce methane production by 20% and increase the production of volatile fatty acids in cows fed grass silage.

Homoacetogens are another group of bacteria that can produce acetate. These bacteria reside in the rumen and can utilize sugars as their energy source. Additionally, they can survive by using H2 and CO2, assisted by a hydrogenase enzyme via the Wood-Ljungdahl pathway. The identified homoacetogens include Acetitomaculum ruminis, Eubacterium limosum, Blautia schinkii, and

Blautia producta. Studies indicate that acetogenesis might present another pathway to remove H2 from the rumen. However, these bacteria are not as abundant as the methanogens, and even high concentrations of acetogens are not capable enough to compete with methanogens for H2. Therefore, their importance in the rumen remains uncertain (Lopez et al., 1999).

Methane-oxidizing bacteria (MOB) are a unique type of bacteria that thrive solely on CH4 as their carbon and energy source. MOBs can survive in various environments, from slightly oxygen-depleted to fully aerobic conditions. MOB employs a specialized enzyme called methane monooxygenase (MMO) to convert methane into methanol through a process known as methane oxidation. The methanol is then further processed into formaldehyde and used in a pathway for biomass synthesis (Khatri et al., 2021).

Despite some research on methane oxidation and enriching MOB in ruminants, the potential of MOB as a probiotic for cattle has not received much consideration. The estimated percentage of methane oxidation carried out by microbial cells from mixed rumen microbes of sheep is around 0.2-0.5% using carbon isotope labeling. MOB was also found in both rumen fluid and rumen epithelium from non-lactating Holstein cows. In vitro, experiments showed a decrease in methane accumulation when MOB isolated from young pigs was introduced. Different strains of MOB have been identified and enriched from various sources, including Bos indicus steers and the feces of an Indian antelope. These bacteria show promising capabilities in utilizing methane and methanol.

## Genetic Selection

One of the promising strategies in methane mitigation is the genetic selection of low methane-releasing ruminants. Genetic markers linked with methane production are being explored. This cutting-edge approach studies the intricate genetic makeup of cattle and other ruminant species to identify specific genetic markers associated with reduced methane production. Besides other methods, the continuity and permanent nature of this method make it more sustainable. Leveraging the power of genetics, scientists strive to breed livestock with inherent traits that promote reduced methane emissions, while safeguarding animal health and productivity.

Above 90% of the methane is emitted and absorbed from the rumen into the blood, and exhaled through the lungs. Various factors like physiological state, environmental stress, lactation periods, and climate change affect CH4 emission. To get a conclusive output from the recorded data, there should be a strict correlation between the above-mentioned factors along with the phenotype and genotype of the ruminants (Hickey et al., 2022). High-yielding animals are the primary choice for the study as they can efficiently convert the feed, will have a healthy body and fewer ruminants will be required to reach a target production level.

### Alternative Livestock Farming Systems

As the global concern over methane emissions from ruminant animals like cattle, sheep, and goats intensifies, there is a growing interest in exploring alternative livestock farming systems that can help mitigate these emissions. Some research focuses on alternative livestock farming systems, such as integrating cattle into agroforestry or silvopasture systems. These systems combine trees, forages, and livestock in ways that can help sequester carbon and reduce the environmental impact of cattle farming (Varijakshapanicker et al., 2019).

Regenerative grazing, a sustainable approach, embraces the intricate interactions between livestock and their environment. This holistic method mimics nature by promoting diverse pastures and rotational grazing. By allowing animals to graze and then rest, the method fosters soil health-enhancing-nutrient cycling and minimizes the need for artificial inputs (Teague & Kreuter, 2020). Moreover, this practice bolsters carbon sequestration in the soil, thus mitigating climate change impacts. Central to regenerative grazing is the concept of regrowth periods for pastures, allowing them to recover and revitalize naturally. By fostering a harmonious relationship between livestock and the land, this approach ensures sustainable food production while restoring the health, and vitality of ecosystems. It also helps mitigate methane emissions in several ways like Improved forage quality, enhanced digestive efficiency, soil carbon sequestration, and reduced stress (Çakmakçı et al., 2023).

Economic and Social Implications:

When estimating the economic consequences of methane emissions from cattle, it is important to take into account several factors that may have an impact on energy use, agriculture, and public health. As per the latest survey of the Intergovernmental Panel on Climate Change, agribusiness alone is anticipated to be responsible for between 10 and 12 percent of the world's greenhouse gas emissions. By 2030, emissions from this industry are predicted to increase by up to 50 percent. Currently, agriculturally-induced land usages such as deforestation, overgrazing, and turning pasture into arable land, are responsible for an additional 6–17% of global greenhouse gas releases (United States Environmental Protection Agency, 2022).

The world's greenhouse gas emissions come from livestock production. The actions encompass deforestation aimed at creating grazing areas and producing soy-based feed, depletion of soil carbon in grazing fields, energy consumption for cultivating and transporting feed crops and meat, emissions of nitrous oxide from the application of nitrogen fertilizers, as well as emissions of gases such as methane and enteric fermentation from animal manure. (Ritchie et al., 2020). Cattle methane emissions combine with other air pollutants to generate ground-level ozone and particulate particles. Ozone at ground level and small particulate matter (PM2.5) are well-known air pollutants that can harm respiratory and cardiovascular health. Additionally, poor air quality can cause health issues leading to lower work capacity, which affects the social economy.

Methane emissions contribute to climate change, which can result in changes in weather patterns and a rise in the frequency of extreme weather changes. Disasters such as hurricanes, floods, and wildfires can impact energy infrastructure, encompassing power plants, transmission lines, and distribution networks. These interruptions may result in power outages and damage to energy infrastructure, which will raise the cost of repair and replacement. Extreme heat events may also increase the need for cooling and air conditioning, thereby increasing energy in hot climates (United States Environmental Protection Agency, 2022).

Approaches for reducing methane emissions from the cattle industry can have many economic advantages beyond environmental ones. Some of the potential financial benefits include

**High Efficiency and Productivity:** Efficient cattle operations such as improving feed quality and management can be achieved by implementing methane-reducing strategies. This can enhance cattle growth rates, reproduction, and overall health, thus resulting in higher yields of milk and meat, ultimately increasing farm income.

**Cost Savings:** Farmers can lower feed expenses and attain desired product level by using more accurate feeding techniques and managing diets to reduce methane production.

**Enhanced Market Access and Consumer Demand:** Cattle farmers who adopt methane reduction practices can attain consumer attention and a hold in markets, as consumers prefer eco-friendly products.

**Long-Term Sustainability:** Methane reduction is a sustainable practice that can contribute to the long-term viability of cattle operations. This can lead to stable revenue generation over time and mitigate the risk of negative economic impacts from future environmental regulations or market shifts.

**Incentive Programs and Subsidies:** Government and other organizations offer incentives and subsidies for practicing environmental friendly approaches. Participating in such programs can provide direct financial support to farmers, and assist in balancing out the expenses associated with executing these stratergies.

**Research and Innovation:** Developing and implementing methane reduction technologies can direct innovation within the cattle industry. Producers who invest in the research and development field may gain a competitive edge and potentially license or sell their innovations to other operations.

**Reduced Health Care Costs:** Healthy cattle resulting from improved feeding and management practices can lead to reduced veterinary and healthcare costs. This contributes to overall cost savings for cattle farmers.

**Mitigation of Climate-Related Risks:** By managing methane emissions, cattle producers can mitigate climate-associated potential risks such as extreme weather events or changing precipitation patterns. This proactive approach can help protect cattle operations from climate-related financial losses.

## POLICY AND REGULATION

A remarkable increase in methane emissions is expected in the coming years. According to the United Nations Framework Convention on Climate Change (UNFCCC), approximately one-third (33%) of global livestock methane emissions are currently attributed to Annex 1 countries, while the remaining two-thirds (67%) are contributed by non-Annex 1 countries. It is projected that non-Annex 1 countries will account for the majority of the anticipated future growth in livestock methane emissions (Jones et al., 2023).

## 1. The Kyoto Protocol

The Kyoto Protocol is a global treaty introduced in 1997 as an amendment to the UNFCCC. It sets mandatory goals for emission reductions for developed nations and transitioning economies. (Kim et al., 2020). On February 16th, 2005, the Kyoto Protocol came into effect. Currently, the Kyoto Protocol has the participation of 192 Parties. As a result of the Kyoto Protocol, greenhouse gas emissions from industrialized nations have decreased. Emissions from Annex I Parties to the Protocol decreased by 5.2% below 1990 levels during the first commitment period. The ability of the Protocol to achieve its ultimate goal of stabilizing greenhouse gas concentrations in the atmosphere is uncertain due to the subsequent increase in the emissions index.

## 2. The Paris Agreement

The Paris Agreement is an international agreement within the United Nations Framework Convention on Climate Change (UNFCCC), highlighting the importance of limiting global warming below 2 degrees Celsius, and preferably below 1.5 degrees when compared to pre-industrial levels. The Paris Agreement was agreed upon by 196 Parties during the 21st Conference of the Parties (COP21) held in Paris, France, on December 12, 2015, and officially came into effect on November 4, 2016.

The agreement comprises several provisions that could aid in lowering methane emissions from the livestock sector, including promoting eco-friendly agricultural methods and funding the development of innovative methane-reduction technologies. The Paris Agreement has three main objectives:

1. To limit global warming emissions.
2. To acclimatize to the effects of climate change.
3. Implementing a bottom-up strategy in which nations submit their own nationally determined contributions (NDCs) to reduce greenhouse gas release to reach these goals.

The Paris Agreement is the first global agreement on climate change that both developed and developing countries have ratified. Additionally, it sets high standards for reducing global warming and preparing for its effects. Despite its flaws, the agreement represents a significant step forward and offers a foundation for future international climate change action (UNFCCC, 2015).

### 3. The European Union's Emissions Trading System

The European Union's Emissions Trading System (EU ETS) has received a lot of attention as the first cap-and-trade program for CO2 emissions in the world. The EU ETS was launched in 2005 and covers about 45% of the EU's greenhouse gas release. The system is divided into three trading periods: The first phase(2005-2007) of the ETS was a trial period, and it covered only the power sector. The second phase(2008-2012), expanded to cover the manufacturing and aviation sectors. The third phase (2013-2020), further expanded the system to cover more sectors and to include more stringent emissions targets.

The EU ETS has successfully decreased emissions of greenhouse gases. Releases from the covered sectors decreased by 21% throughout the system's first three phases. New techniques and technology that lessen greenhouse gas emissions are said to have been sparked by the EU ETS (European Commission, 2022).

### 4. Sectoral Policy Approach

Sectoral policy approaches focus on reducing emissions from specific sectors of the economy, such as agriculture, energy, or transportation. It involves the implementation of specific policies and measures aimed at improving the efficiency of greenhouse gas mitigation from different sectors, operating within the framework of the United Nations. The specific emission goals may differ from country to country as they work towards sector-specific mitigation strategies.

In 1970, the non-profit organization The Natural Resources Defence Council (NRDC) was established. It has over 3 million members and online activists, and a staff of about 700 scientists, lawyers, and other environmental specialists. The mission states that it works "to protect nature in ways that advance the long-term welfare of present and future generations”. It also emphasizes a way of life "that can be sustained indefinitely without pollution or depleting the resources that support all life on Earth”. It focuses on a variety of environmental concerns, such as climate change, clean energy, air and water quality, wildlife protection, sustainable agriculture, and the conservation of environmental assets.

To address environmental challenges, the United Nations Environment Programme (UN ENVIRONMENT) has a particular relationship with civil society. A pivotal turning point in the regulation of the environment was the Stockholm Conference on the Human Environment, which took place in 1972. The United Nations Environment Programme (UNEP) was founded as a result, and it recognized the significance of including civil society in environmental decision-making processes. The success of the conference was greatly aided by the passion, commitment, and dedication of civil society, which includes non-governmental organizations (NGOs).

The livestock industry's methane emissions could be decreased by several potential upgrades or new actions. These actions include modification of feed additives which reduce methane production, improved manure management, breeding livestock using genetic selection, etc. The implementation of clean and renewable energy technologies may accelerate the transition away from fossil fuels if governments increase incentives and funding for their development. Promoting campaigns to raise public awareness about climate change can aid in educating people about its importance and promoting sustainable lifestyles.

By recognizing the potential economic advantages that extend beyond environmental benefits, investors in the cattle industry can position themselves for success characterized by heightened environmental awareness, regulatory shifts, and changing consumer preferences. As this white paper has outlined, embracing methane reduction strategies contributes to mitigating climate changes and a spectrum of economic incentives, ranging from enhanced productivity and cost savings to improved market access and innovation. By aligning environmental stewardship with economic viability, the cattle industry can forge a path toward sustainability that is both environmentally responsible and economically prosperous.

## CONCLUSION

Methane emission from cattle is a pressing environmental issue that significantly contributes to global warming and the intensification of climate-related challenges. Various mitigation strategies including dietary interventions, genetic selection, feed additives, breeding techniques, and technological innovations have been researched and proposed to reduce methane emissions and advance sustainability. Policy and regulation significantly contribute to promoting sustainable practices and the adoption of innovative technologies. Ongoing research and technological advancements offer promising solutions to tackle this challenge effectively. Embracing these measures not only benefits the environment but also carries important economic and social implications, ensuring a more sustainable and resilient future for coming generations.

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