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School of International and Public Affairs

ENTERIC METHANE INNOVATION TOOLS FOR LOWER EMISSION AND SUSTAINABLE STOCK ACT | S. 4056

WORKSHOP IN APPLIED EARTH SYSTEMS MANAGEMENT
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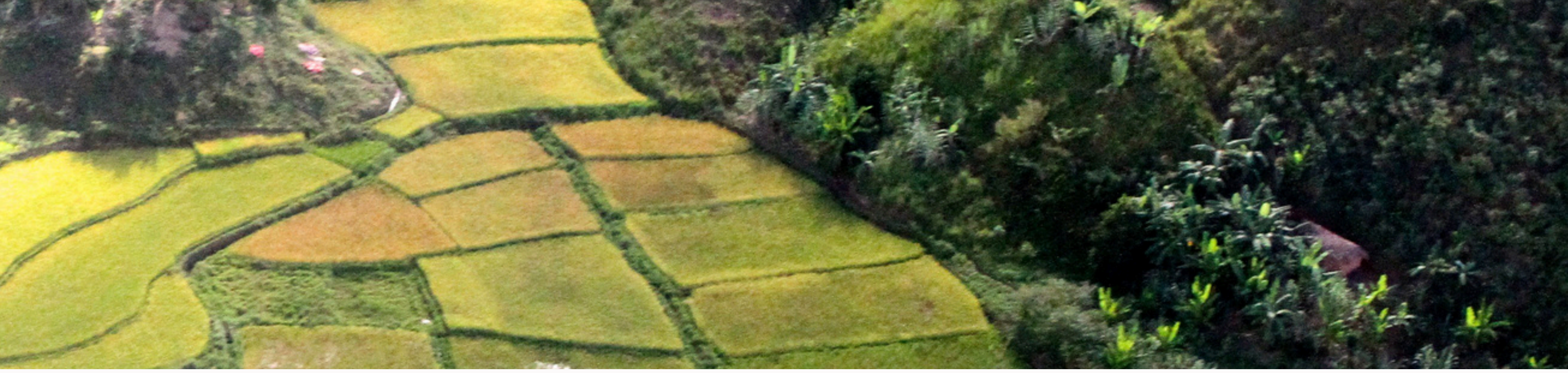

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01.
EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

Methane is a potent greenhouse gas that contributes significantly to the worsening of climate change, being 86 times more potent than carbon dioxide over a 20-year lifespan. Enteric fermentation in ruminant cattle is a major source of methane emissions in agriculture. In fact, 40% of anthropogenic methane emissions stem from agriculture, of which 90% originate from cattle. However, the topic has received relatively little attention in policy compared to other sources of greenhouse gasses, like fossil fuels.

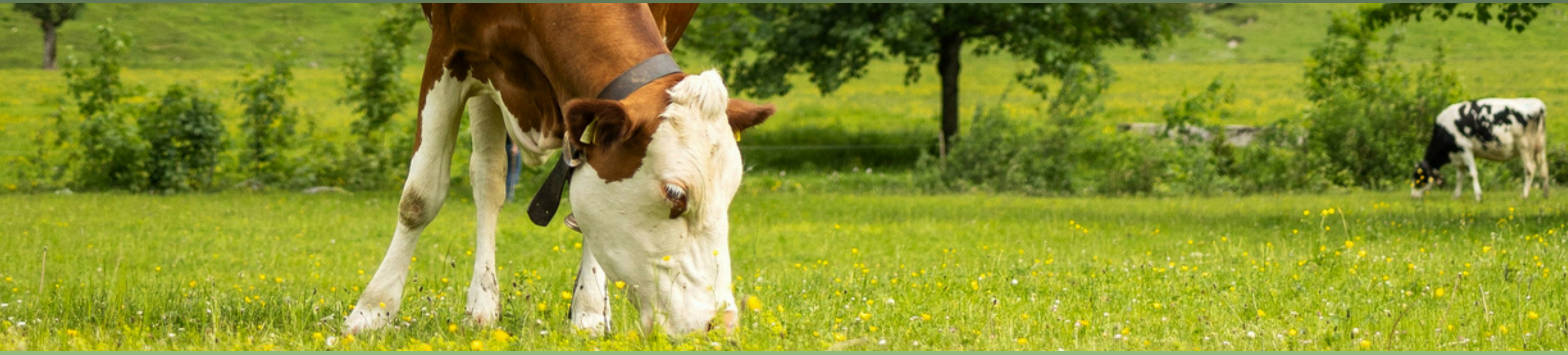
The Enteric Methane Innovation Tools for Lower Emissions and Sustainable Stock (EMIT-LESS) Act of 2024 (S. 4056) is a bipartisan proposed bill that aims to promote a sustainable shift in the cattle industry by addressing methane emissions from ruminants, primarily cattle. Introduced by Senator Michael Bennet (D-Colorado), the Act has the objective of reducing methane emissions by funding enteric methane reduction research, expanding training programs for farmers to adopt reduction practices, and promoting sustainable livestock management practices through financial incentives.

The Act calls upon the Secretary of Agriculture to promote research within the United States Department of Agriculture as well as at independent universities and research institutions. This includes developing infrastructure for measuring methane emissions, understanding their impact on animal productivity, growth and health, and the effectiveness of different livestock management practices.

To reduce methane emissions, several practices have been and are being developed, including altering cattle diets, using feed additives, early-life interventions, selective breeding, genetic manipulation, vaccination, and improved manure management. Each of these strategies requires further research, as there are possible issues related to their effectiveness, health implications on cattle, productivity influence, cost-effectiveness, and whether there are any ethical issues involved.

The success of the EMIT-LESS Act can be measured using direct and indirect indicators. The most important direct indicators will be the reduction in methane emissions from cattle as well as the reduction of atmospheric methane emissions. Indirect indicators, however, will allow the USDA to manage and administer their program better. These include the volume of research funded and the output produced, the number of training programs offered, the number of farmers adopting methane-reducing solutions after going through the training program, and the reduction of methane emissions per farmer that receive financial compensation for implementing the practices. Different technologies are available to track progress and steer the USDA's efforts in the right direction.

The EMIT-LESS Act represents a significant step towards addressing one of the most substantial sources of anthropogenic greenhouse gas emissions. By funding innovation and incentivizing the implementation of sustainable livestock management practices, the Act will be crucial for the United States's climate change mitigation efforts and the world's ambition to limit global warming according to the Paris Agreement.



02. LEGISLATIVE SUMMARY

LEGISLATIVE SUMMARY

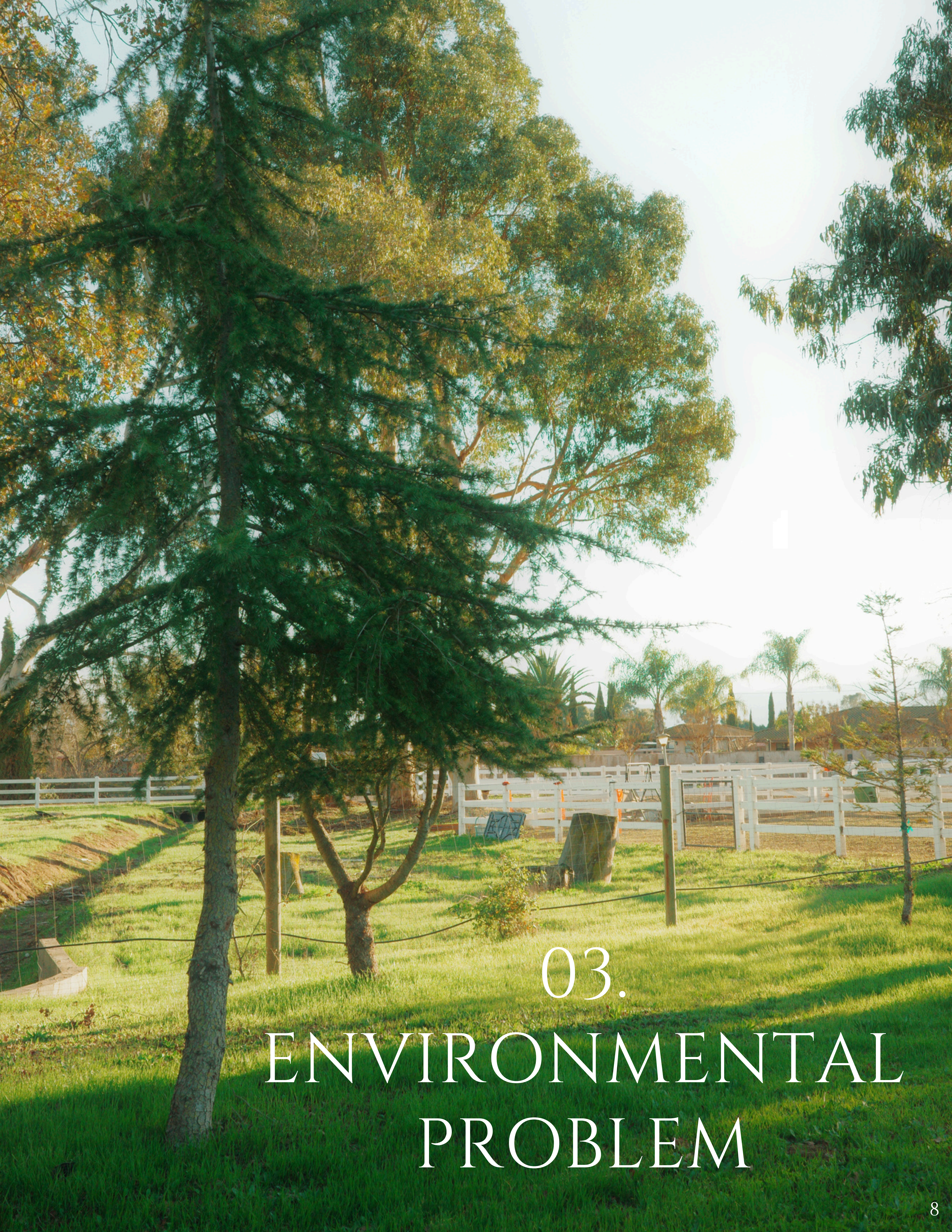
The Enteric Methane Innovation Tools for Lower Emissions and Sustainable Stock (EMIT-LESS) Act (S. 4056) is a bipartisan legislation introduced by Senator Michael Bennet (D-Colorado) in collaboration with Senators Mike Crapo (R-Idaho), Tammy Baldwin (D-Wisconsin) and Jerry Moran (R-Kansas). The Act aims to promote sustainability in the agricultural sector by addressing enteric methane emissions produced by ruminant digestion. The bill revises and expands current enteric methane reduction practices, promotes innovative research, and creates incentive programs for farmers in an effort towards reaching the US Global Methane Pledge (Malley et al., 2023).

The EMIT-LESS Act places responsibility on the Secretary of Agriculture and the United States Department of Agriculture (USDA) to conduct research on enteric methane reduction strategies. Through the Agricultural Research Service, the principal research agency of the USDA, the Act aims to administer and fund solution-oriented research related to enteric methane emissions of ruminant feeders, most notably cattle. The Secretary is responsible for providing the infrastructure needed for studying baseline enteric methane emissions, the impact of enteric methane production on animal productivity and health, and the impacts of methane mitigating practices on greenhouse gas (GHG) emissions and animal welfare. This infrastructure may include constructing or renovating facilities, collaborating with stakeholders such as independent and academic research facilities, and purchasing appropriate technology for research assessment (EMIT-LESS Act, S. 4056, 118th Cong., 2024).

With its research and development component, the EMIT-LESS Act will create training and payment programs for ranchers to effectively adopt innovative methane-reducing solutions while mitigating the cost of transition. Under the Food Security Act of 1985, the EMIT-LESS Act requires that the Secretary of Agriculture establish one or more studies regarding enteric methane emission reductions alongside a comprehensive report outlining the study's innovation, economic outcomes, and reduction of GHG emissions.

The EMIT-LESS Act additionally requires the Secretary of Agriculture to organize a review of the latest conservation practice standards on feed management and enteric methane emission reduction practices. It will furthermore create payment programs to compensate farmers for the cost of implementing methane-reducing solutions and practices as well as forgone income (EMIT-LESS Act, S. 4056, 118th Cong., 2024).

The EMIT-LESS Act is an innovative legislation proposing a sustainable shift in the dairy and livestock industry. By expanding research and development regarding enteric fermentation reduction strategies, the EMIT-LESS Act will establish the path to the reduction of enteric methane emissions. Through the creation of payment programs ranchers will have the incentive and ease of transitioning to more sustainable practices with fewer or no financial drawbacks. Through these efforts, the U.S. will move closer to achieving the goals of the Global Methane Pledge, which seeks to reduce anthropogenic methane emissions by 30% by 2030 (Malley et al., 2023).



03. ENVIRONMENTAL PROBLEM

ENVIRONMENTAL PROBLEM

The significant increase of GHG emissions pose a significant threat to our planet as they accelerate climate change, heating up the planet to dangerous levels. Methane is of particular concern due to its potency as a GHG; it is 86 times more potent than carbon dioxide over a 20-year lifespan (IPCC, 2022). Although methane makes up only 16% of global greenhouse gas emissions, it is, in fact, responsible for 30% of global warming thus far (IPCC, 2022). Cattle represent the principal source of methane emissions from agriculture, which makes up about 40% of anthropogenic US GHG emissions (EPA, 2022). This means that if methane emissions remain at current levels, they will exacerbate global warming and climate instability.

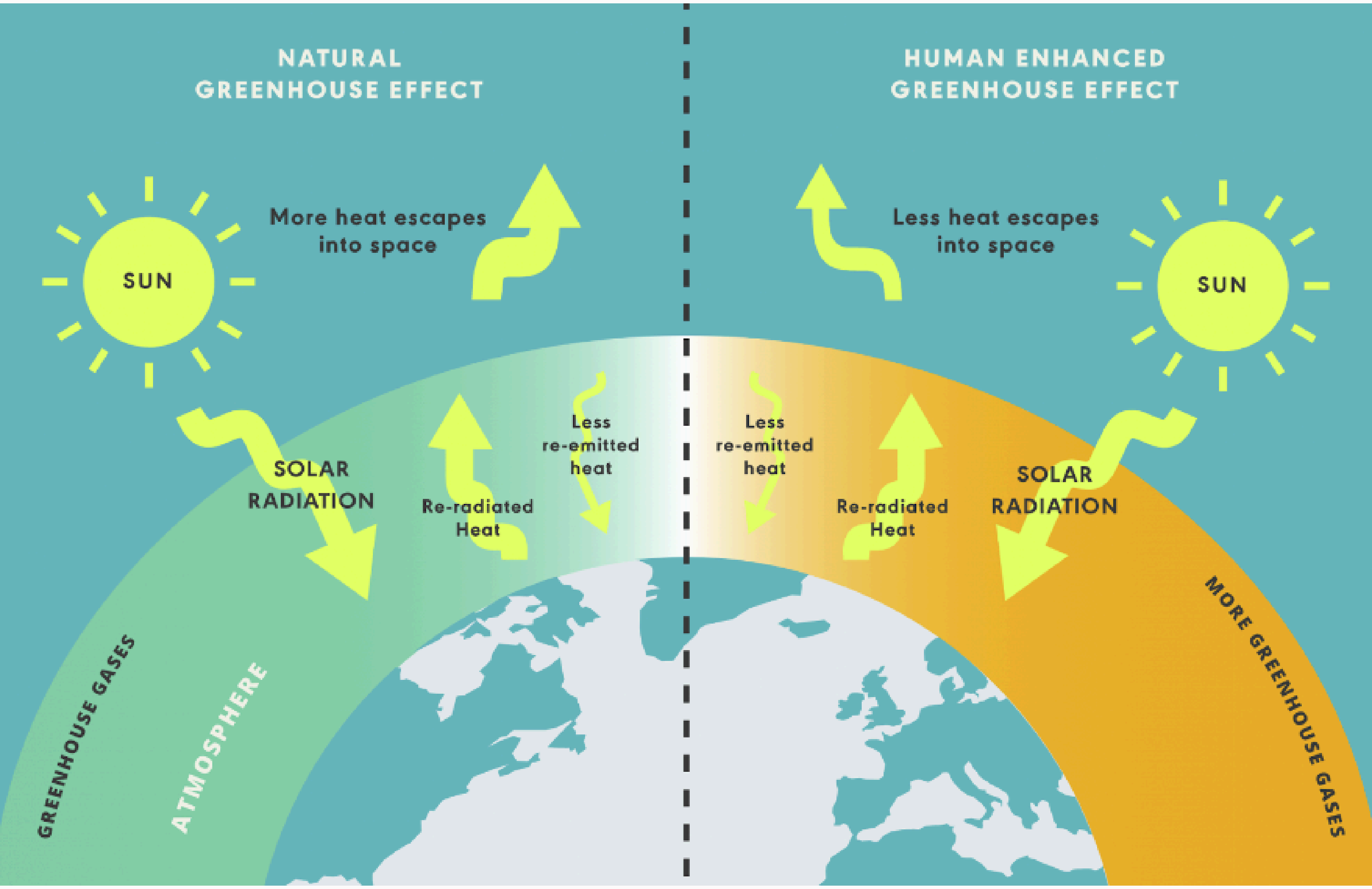


Figure 1: Natural and human-enhanced greenhouse gas effect; source: RNC2050 (n.d.)

3.1 Enteric Fermentation as a Major Source of Methane Emissions

Enteric methane emissions result from enteric fermentation in ruminants. Ruminants break down complex carbohydrates in their rumen through microbial decomposition, producing methane as a byproduct and releasing it primarily through eructation. Ruminants—such as cattle, sheep, and goats—have a specialized digestive system for this process, differentiating them from other land mammals. What makes the digestive system of ruminants unique is their four-chamber stomach, which comprises the rumen, reticulum, omasum, and abomasum (see Figure 2) (Gibbs et al., 2001).

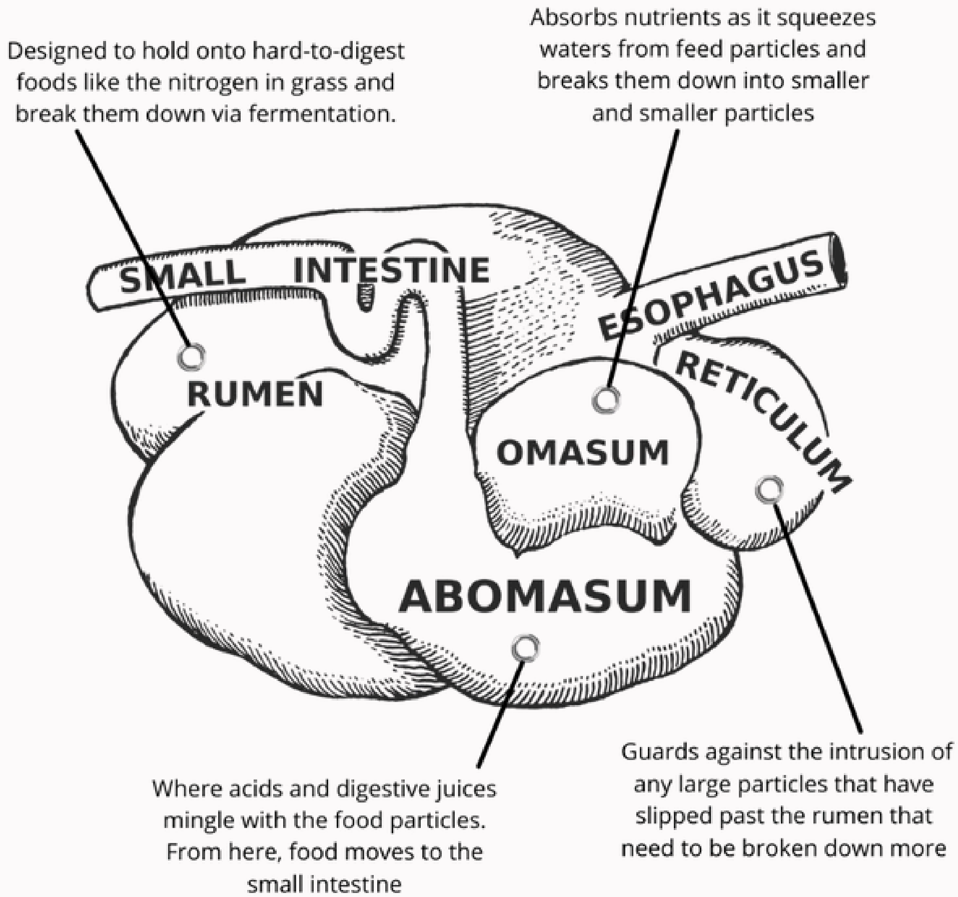


Figure 2: Cattle Stomatch; source: GO Seed (2021)

Enteric fermentation takes place in the rumen, where over 200 unique strains of microorganisms (including bacteria, protozoa, and fungi) are responsible for the enteric fermentation process, allowing ruminants to effectively digest the complex carbohydrates in plant matter by breaking down their lignocellulosic structures (complex and irregular lattice structure of plant walls) into monosaccharides (simple sugars) (Sanjorjo et al., 2023).

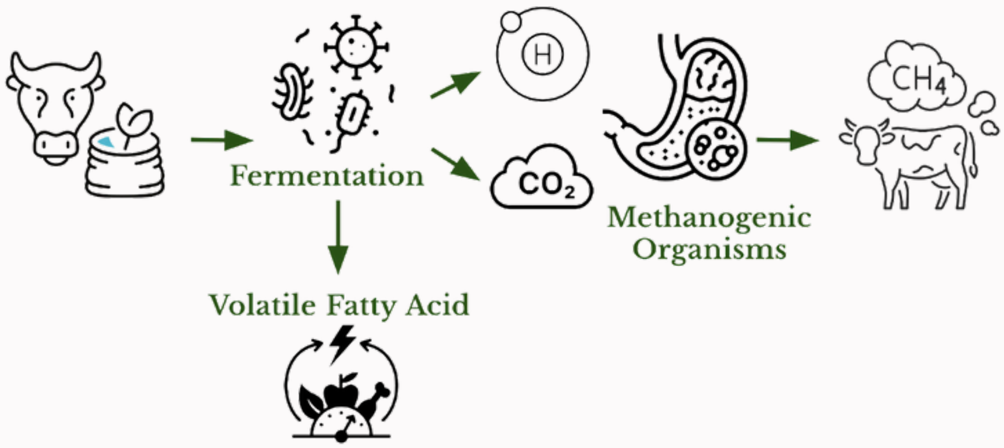


Figure 3: Enteric fermentation: the digestion process

These monosaccharides are then further fermented in the rumen and break down into various products including volatile fatty acids (VFAs), carbon dioxide (CO_2), and hydrogen (H_2). The VFAs are utilized for energy, while the methanogenic archaea, a microorganism in the rumen, produce methane (CH_4) and water (H_20) in a process known as methanogenesis (Smith et al., 2022). During this process, microbial metabolic activities result in the production of cellular energy in the form of adenosine triphosphate (ATP) (Vetriani, 2001). Further mechanical breakdown occurs in the reticulum and omasum, preparing food for final digestion in the abomasum. The methane produced during enteric fermentation is then primarily released through eructation (burping). A smaller amount of methane (approx. 5%) is also produced further along the digestive tract and is emitted through the cow's manure (cf. Figure 4) (Sanjorjo et al., 2023).

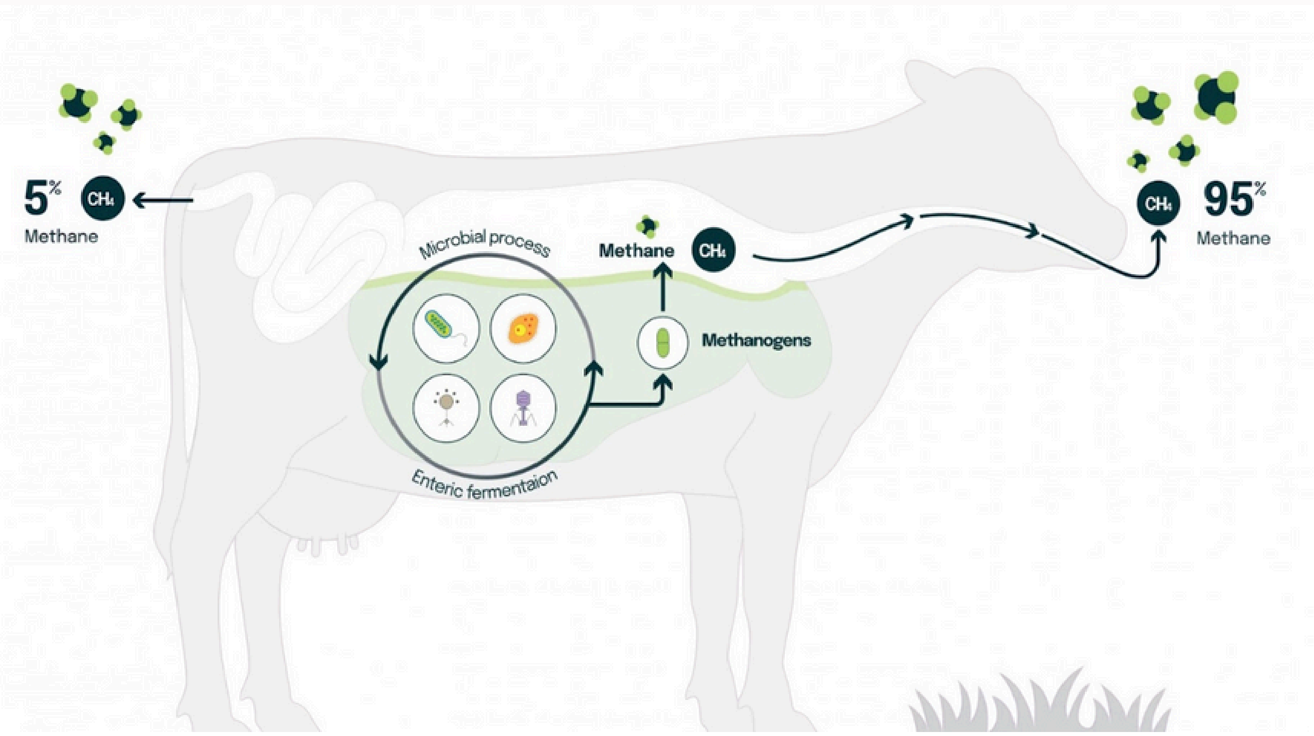


Figure 4: Sources of methane emissions from cattle; source: New Zealand Agricultural Greenhouse Gas Research Centre (2021)

In the US, enteric fermentation accounts for approx. 25% of total methane emissions, the second largest source after natural gas and petroleum systems (US EPA, 2023). Despite this, methane emissions from enteric fermentation have received little policy attention compared to fossil fuel emissions. This bill aims to fill this policy gap by developing a framework for implementing new standards to limiting methane emissions from enteric fermentation moving forward.

3.2 Agricultural Sustainability and Climate Change Impact

Government intervention is crucial for ensuring the long-term sustainability of agriculture. The EMIT-LESS Act can help promote the adoption of sustainable practices by providing financial incentives and technical support to farmers. By investing in research and development of methane-reducing technologies, the United States government can support the transition to more efficient and environmentally friendly farming practices. This is essential for maintaining the productivity and profitability of the livestock industry while reducing its environmental impact.

Climate change is causing increased temperatures, which leads to heat stress in ruminants. Heat stress reduces the productivity and health of livestock, increasing the need for food, water, and veterinary care. These additional costs can be a significant burden on farmers. By reducing methane emissions through the EMIT-LESS Act, the government can, therefore, help mitigate the overall impact of climate change, thereby reducing the frequency and severity of heat stress events. This will help ensure the well-being of livestock and the economic stability of the farming community (Chauhan et al., 2023).

3.3 Background on Current Cattle Farming Management

Cattle are farmed using grazing and confined management methods. Grazing allows cattle to roam free within a larger area and feeding off of naturally occurring plants within the pasture. This is the most common method for cattle farming worldwide. In the US, although various forms of grazing can be seen in dairy systems, grazing is most commonly seen in cattle raised for beef cattle (Whitt & Wallander, 2022). Different from grazing, confined farming restricts the animals movement to a specific highly managed area, either outdoors or indoors. Many dairy practices use confined farming, while beef cattle farming, especially in western countries, will move from grazing to confinement in feedlots during the final months before slaughter (Alonso, 2023). Such transition helps enhance weight gain and meat quality through feeding specific controlled diets. This confinement does not provide access to naturally growing plants but does provide farmers with enhanced control of intake and production while reducing land use. It also requires intensive manure management while providing increased biosecurity and protection from predators and adverse environmental conditions.

Cattle diets fed in confined farming consist of five major ingredients: forages, grains, protein supplements, vitamins and minerals, and additives (V. Ishler, 2024; V. A. Ishler et al., 2023). Harvested forages, colloquially referred to as hay, include grasses and legumes. Legumes are very nutrient rich, while grasses have lower levels of nutrients, but both of them are the source of the majority of carbohydrates. Grains provide a concentrated, highly digestible source of energy in the form of fatty acids and are high in protein, contributing to muscle and body development. Typical grains used for feeding cattle are corn, wheat, oat, and barley. Protein supplements, vitamins and minerals, and additives are used for further body development and improved health and are commonly used for dairy cattle in the form of the total-mixed ration (TMR), a type of ration that combines multiple feeds into one mix (Ishler V. A. et al., 2023).

In modern dairy farming, various confined management housing systems address the needs of cattle while managing waste differently. So called tie-stall barns confine each cow in a stall, with manure collected in gutters behind them. Free-stall barns allow cows to roam within defined areas, with manure removed from the floors regularly. Hoop barns, resembling tents, offer shelter and natural ventilation, using straw bedding that absorbs manure and urine. This system requires regular replacement with fresh straw to avoid the buildup of waste. In contrast, pasture-based systems allow cattle to graze openly, where manure is naturally deposited and helps fertilize the fields, integrating waste management with feeding and grazing practices. Each system balances animal welfare, waste management, and operational efficiency differently to support dairy farming practices (Poteko et al., 2019).

3.4 Future Direction for Cattle Management to Reduce Methane Emissions

Methane emissions from livestock, particularly from enteric fermentation in ruminants like cattle, pose significant environmental concerns due to methane's potency as a GHG. Advances in understanding microbial interactions within the digestive systems of these animals offer promising avenues for targeted interventions aimed at reducing methane production. Improved feed management practices, such as optimizing dietary composition and feeding schedules, play a crucial role in mitigating methane emissions from enteric fermentation. These efforts not only contribute to environmental sustainability but support more efficient livestock production practices globally.

04. Reducing Methane

REDUCING METHANE

While no specific strategies are being proposed in the EMIT-LESS Act to reduce methane emissions, there are several solutions being developed to decrease methanogenesis. These are broadly split into feed management, advanced interventions, and manure management strategies. Feed management strategies change the diet and include altering the diet composition, feed additives, and early life or fetal interventions. Advanced solutions include non-traditional methods like selective breeding, genetic manipulation, and vaccinations. Feed management strategies and advanced solutions target methane from enteric fermentation while manure management targets the methane emissions that arise later in the digestive process by targeting the diet or managing the manure in a specific way. The following will elaborate what each solution entails, what benefits it brings, and what possible issues or controversies are related to that solution.

4.1 Altering Diet Composition

The most commonly seen practice in alternating diet composition involves adjusting the ratio between the hays and grains contained in cattle diets in a confined feeding system. High-starch diets containing more grains offer more fat and protein which are easier to break down into volatile fatty acids and that serve as the energy source for cattle. At the same time, they produce less hydrogen and carbon dioxide as byproducts, leaving less available material to be transformed into methane gas (cf. Figure 3). The reduction also results from high-starch diets favoring the production of propionate over acetate during fermentation, which uses hydrogen that would otherwise contribute to methane production through the methanogenic process (Haque, 2018; Lileikis et al., 2023).

Dietary strategies, however, need careful implementation to avoid health issues. Excessively high grain levels can lead to overproduction of volatile fatty acids, increasing rumen acidity and disrupting the microbial environment necessary for fermentation. This disruption can cause serious digestive issues like acidosis, laminitis, and rumenitis, compromising cattle health and productivity (Owens et al., 1998; Tseten et al., 2022).

Maintaining a balanced diet is thus crucial to avoid these adverse health effects. The focus should be on optimizing grain levels to achieve methane reduction without harming cattle health. This approach requires continuous monitoring and adjustment of feed to maintain an optimal rumen environment, supporting both methane reduction and cattle well-being (Gerber et al., 2013).

4.2. Feed Additives

Feed additives are substances put on the top of or mixed into the diets of cattle in a controlled diet system, where they are fed with specific types and amounts of food. Plant-based additives include saponins, tannins, essential oils, and a mixture of garlic powder and citrus extract. Probiotic, prebiotic, seaweed, and 3-nitrooxypropanol are other forms of feed additives. Feed additives are supposed to improve feed quality, promote growth, and alleviate nutrient deficiencies.

- **Asparagopsis**, a sub-tropical red seaweed, reduces methane production in ruminants primarily through its content of volatile halogenated compounds, particularly bromoform. Bromoform acts as an anti-methanogenic agent, effectively reducing enteric methane emissions by more than 80% in some studies. This reduction is achieved by altering the rumen microbiome, which is responsible for methane production during the digestive process in ruminants (Wasson et al., 2022).
- **3NOP (3-Nitrooxypropanol)** is a synthetic feed additive specifically designed to block methane formation in the rumen, inhibiting methanogens. 3NOP prevents them from using hydrogen to produce methane. As a result, hydrogen accumulates in the rumen and is emitted as hydrogen gas instead of being converted into methane (Clear Center, 2021; Lopes et al., 2016).
- **Tannins** reduce methane production by affecting the microbial population in the digestive system, altering fermentation processes, and potentially inhibiting methanogen activity. They achieve this through mechanisms such as exerting a direct toxic effect on methanogens, reducing the number of protozoa, forming protein-tannin complexes, and inhibiting protease enzyme activity in the rumen. Tannin sources have been studied for their impact on methane reduction, showing varying degrees of effectiveness in reducing methane production percentages ranging from 14% to 67% (Jafari et al., 2019).
- **Saponins** reduce methane production by targeting protozoa in the rumen, indirectly affecting methane emissions. They disrupt the cell membrane of protozoa, leading to and disrupting the microbial environment necessary for fermentation. This disruption can cause a decrease in protozoa numbers. Studies have shown that saponins can mitigate methane emissions by affecting the microbial population in the rumen. Their mechanism of action involves inhibiting protozoa, which play a role in methanogen populations, thus indirectly impacting methane production (Jafari et al., 2019).
- **Essential oils** reduce methane production through a direct toxic effect on methanogens. The antimicrobial properties of essential oils target methanogens specifically, inhibiting their growth and activity, thereby reducing methane emissions. By disrupting the methanogen population, essential oils can alter the fermentation processes in the rumen, leading to a reduction in methane production (Jafari et al., 2019).
- **Nitrates** are naturally occurring chemicals that reduce methane emissions by competing with methanogens for hydrogen in the rumen. They can lower methane emissions by up to 16% in dairy cattle and 12% in beef cattle (Clear Center, 2021).

- The **mixture of garlic powder and citrus extract** is marketed under the brand name Mootral (Mootral, 2023). The citrus extract works by alternating the microbial community in the cattle's rumen, elevating the efficiency of the fermentation process, thus allowing the fermentation process to break down more volatile fatty acids with less byproducts of hydrogen and carbon dioxide (Vrancken et al., 2019). The active compounds in garlic, on the other hand, contain antimicrobial properties that inhibit methane-producing microbes, leading to overall lower methane production (Sari et al., 2022).

CASE STUDY

A case study, where lactating cows received 500 g of pellets containing 3% Mootral powder for 12 weeks showed significant success. After supplementing the diet of Jersey and Holstein Friesian cows with Mootral, **methane reductions of 38% and 21%** were observed, respectively, with an overall average reduction of 30%. Meanwhile, **milk yield increased by 5-8%** and somatic cell counts were lowered without negative health impacts (Mootral, 2023; Vrancken et al., 2019).

- **Probiotics** are live microorganisms that confer a health benefit on the host when administered in adequate amounts, while prebiotics are non-digestible food ingredients that selectively stimulate the growth and/or activity of the beneficial microorganisms in the gut (Sun et al., 2021). These live microorganisms can reduce methane emissions in ruminants through various mechanisms, such as outcompeting methanogens for hydrogen. Both probiotics and prebiotics can reduce methane production and improve animal health and feed efficiency (Kulkarni et al., 2022).

Despite broad evidence of success, feed additives must be carefully implemented to avoid health issues. For instance, asparagopsis, which contains bromoform, significantly reduces methane emissions but does so by altering the rumen microbiome, which could have unknown long-term effects on the health and digestive efficiency of ruminants. Similarly, 3NOP leads to hydrogen accumulation in the rumen, which is then emitted as hydrogen gas, potentially affecting the overall gas balance and microbial ecosystem. Tannins, saponins, and essential oils modify the microbial population and fermentation processes in the rumen, which could disrupt the natural balance of the digestive system (Jafari et al., 2019; Lopes et al., 2016; Wasson et al., 2022). When using nitrate as additives, the nitrate levels within the cattle must be carefully monitored to prevent toxicity from nitrite formation (Clear Center, 2021). The effectiveness of all feed additives also varies across different cattle breeds and environments, requiring specific dosages and combinations (Tseten et al., 2022; Uyeno et al., 2015). Finally, to maintain benefits, a continuous use of the additives is necessary, which increases costs and poses challenges for small-scale farmers (Sun et al., 2021). More research is needed to fully understand their mechanisms and long-term impacts, ensuring sustainable and cost-effective use.

4.3. Early Life or Fetal Interventions

Reducing methane emissions through interventions during the fetal or early months of life includes adding supplements in feed during pregnancy, or right after birth, to alter the development of the microbial community of the newborn to favor lower methanogenesis. These interventions include increasing fats and decreasing fiber in the pregnant cow's diet, along with adjustments of feed additives.

CASE STUDY

In a study in Nellore cows, a commonly farmed beef breed in Brazil, complete nutritional programming for pregnant cows led to a 20% increase in propionate-producing bacteria, which aids in the fermentation process of carbohydrates in the digestive pathway. Consequently, a 25% reduction in methane-producing archaea, which play a vital role in converting the hydrogen produced in the digestion process into methane, were observed, resulting in a 20% decrease in methane emissions (Dias et al., 2024).

Studies indicate that supplementing neonatal calves with 3-nitrooxypropanol (3-NOP) from birth to 14 weeks can reduce methane emissions by approximately 150 kg of carbon dioxide equivalents (CO_2e) in their first year. This reduction is achieved by inhibiting the enzyme methyl-coenzyme M reductase (MCR) which is critical to support the production of methanogens in the rumen of dairy calves, leading to persistent changes without adversely affecting growth or health (Pitta, et al., 2022). One study showed that 3-NOP has lasting effects in reducing methane production for at least a year when treatment ceases at around the newborn's 14th week (Meale et al., 2021). This suggests that these fetal or early dietary manipulations can alter the microbial colonization or microbiome of the rumen and be effective in reducing methane production.

Ideal interventions would show lasting imprint even after supplement treatment stops. However, the outcome is only sometimes lasting and often relatively unstable and highly dependent on factors including farm conditions, the moment when the additive is given, and which type is given to the cattle. Meanwhile, the health effects of these interventions still remain largely unknown due to the complex microbial community dynamics and the lack of research (Meale et al., 2021).

4.4 Selective Breeding and Genetic Manipulation

Selective breeding is the process of selecting organisms to achieve desired traits over generations. When selecting methane reduction as a desired trait, the approach can lead to long-term reductions in methane emissions from livestock, with benefits accumulating over generations (Wall et al., 2010). Selective breeding is effective in both intensive systems, such as feedlots, and pasture systems, like pasture-based farming, thus addressing methane emissions across diverse agricultural practices (Beauchemin et al., 2008). Assisted reproduction technologies further accelerate genetic improvements for traits like lower methane emissions (Fouts et al., 2022).

Selective breeding aims to lower methane emissions from livestock by choosing animals that produce less methane for breeding. This process takes advantage of genetic traits and can lead to a 25% reduction in long-term methane emissions in some cases (Wall et al., 2010). There are several types of selective breeding (Fouts et al., 2022):

- **Direct selection**, which involves selecting low-emitting animals based on phenotype (Pickering et al., 2015).
- **Indirect selection**, which focuses on improving traits correlated with lower methane emissions, such as feed efficiency and reproductive traits (Knapp et al., 2014).
- **Genomic selection**, which is a modern method that uses DNA markers to select animals with desirable traits, such as low methane emissions (Hayes et al., 2016).
- **Combining interventions**, which combines selective breeding with dietary reformulation and feed additives for additive methane reduction (Schilde et al., 2021; X. M. Zhang et al., 2021).

Genetic manipulation used in methane reduction of cattle typically refers to the process of using genome-editing tools such as molecular scissors to directly alter the DNA of either the cattle itself or the methane-producing microbes residing in its digestive pathway. The ultimate goal is to create a lasting reduction of methane emissions without negatively impacting cattle's health or productivity (Menchaca et al., 2020).

Findings have shown that cattle's genetic makeup influences the rumen microbiome distribution, including that of methanogens. Therefore, it is technically feasible to use gene-editing tools to tailor for lowering overall methane production (Roehe et al., 2016). Researchers from the University of California, Davis, found that genetic-editing treatments targeting methane-producing microbes in the cattle's rumen could provide a permanent reduction in methane emissions throughout the cattle's life (Difford et al., 2018; Hess et al., 2011; Sicard, 2023). Similar genetic interventions have shown the potential to decrease methane emissions by up to 50% in certain cattle populations (Wall et al., 2010).

Research is needed to fill knowledge gaps, particularly for regionally appropriate interventions (Dillon et al., 2021). Studies should explore lifetime impacts on methane reduction and animal health, as well as consumer and farmer acceptance of methane mitigation interventions as they are crucial for widespread adoption.

One issue related to this solution is that it takes multiple generations to cross blood lines to create the ideal cattle, and since multiple traits are supposed to be combined, chance plays a role in the success the farmer can achieve. Therefore, the effectiveness to reduce methane emissions is estimated to be low to medium (de Haas et al., 2021; Gerber et al., 2013).

Genetic manipulation techniques, although effective, are usually expensive, which might only make them profitable in the long term. Meanwhile, dealing with genetic code can potentially impact other characteristics like growth or milk production and cause health problems that limit the length of production and life of the animal (Kramer & Meijboom, 2022). Lastly, genetic manipulation also comes with ethical and marketing concerns, as these genetically modified products would require additional authorization when entering certain markets and consumers might choose not to buy these products (European Commission, 2015).

4.5 Vaccinations

Vaccines work by introducing a harmless form of the methanogenic protein into the animal's body, stimulating the immune system by recognizing it as a threat. This triggers the production of antibodies that specifically target and neutralize methanogens in the rumen, reducing their ability to produce methane during digestion (L. Zhang et al., 2015). The development of the vaccine involves several stages. In the first stage, specific proteins that are essential for the growth and function of methanogens are targeted. The second stage involves gene amplification and protein production, where the gene is amplified and cloned into a suitable expression system, such as Escherichia coli (E. coli). In the final stage, the recombinant protein is purified and prepared for use as a vaccine (L. Zhang et al., 2015).

CASE STUDY

ArkeaBio, a Boston agricultural biotechnology firm, is currently working on developing a methane reducing vaccine with the goal of mitigating the effects of climate change (ArkeaBio, n.d.). Vaccines can influence the rumen microbiome, potentially leading to unintended changes in microbial composition, so continued research is necessary to identify more effective vaccine targets and optimize vaccination protocols (Meale et al., 2021).

As is the case for all of the solutions, there are several controversies surrounding vaccinations as well. A perfect vaccine would ideally reduce methane emissions without affecting health and production traits. However, conditions like stability at room temperature during transport and storage affect the effectiveness of the vaccines but can incur high costs, which represents a significant barrier in rural areas (Gerber et al., 2013). Determining the effective frequency of vaccinations, i.e., how often to inject them, also adds complexity. These factors, along with potential negative health effects and high investment costs, make vaccination programs controversial (Gerber et al., 2013; L. Zhang et al., 2015).

4.6 Manure Management

Manure management strategies target the last 5% of methane production that arise post-enteric fermentation in the ruminant. There are three main solutions: altering the diet of livestock to specifically target manure emissions, anaerobic digestion, and composting.

1) Altering the diet of livestock can reduce the amount of methane released from their manure by influencing the composition of the manure and the microbial processes that occur during its decomposition. This involves changing the nutrient profile and digestibility of the feed, which can affect the fermentation process both in the animal's gut and in the manure after it is excreted. Changing the nutrient profile of the feed primarily involves the use of feed additives such as fats and plant-based additives which can reduce methane production from enteric fermentation and ultimately lead to less methane released via manure. A related solution is to increase the proportion of highly digestible feed such as grain and reducing the proportion of fiber in the diet (e.g. replacing corn silage for grass silage), which reduces emissions from manure (Hristov et al., 2013).

2) Anaerobic digestion is the breakdown of organic matter in the absence of oxygen, releasing methane as a byproduct. Controlled anaerobic digestion can be employed to collect the methane and carbon dioxide and use these biogases to generate renewable energy. Controlled anaerobic digestion occurs in a multi-step process that begins with the collection and pretreatment of manure, which is then fed into the anaerobic digester (an enclosed structure devoid of oxygen where produced biogases are collected). The anaerobic digestion process occurs in four stages, which are as follows (Meegoda et al., 2018):

1. **Hydrolysis**: Complex organic materials are broken down into simpler compounds by microorganisms in the anaerobic digester.
2. **Acidogenesis**: These compounds are converted into volatile fatty acids, alcohols, hydrogen, and carbon dioxide.
3. **Acetogenesis**: The volatile fatty acids and alcohols are converted into acetic acid, hydrogen, and carbon dioxide.
4. **Methanogenesis**: Methanogenic archaea convert acetic acid, hydrogen, and carbon dioxide into methane and water.

The methane produced is then collected at the top of the digester to be used for electricity and heat production through its combustion. Alternatively, it can be further refined to remove impurities and produce biomethane that can be sold commercially as natural gas (Meegoda et al., 2018).

CASE STUDY

Denmark has implemented anaerobic digestion as a key component of its agricultural and renewable energy strategy, particularly for managing livestock manure. The approach has yielded significant environmental and economic benefits, serving as a model for sustainable agricultural practices globally. Denmark primarily uses thermophilic anaerobic digestion, which is anaerobic digestion at high temperatures (between 30°C to 40°C / 86°F to 104°F). These elevated temperatures enhance the activity of thermophilic microorganisms, leading to a faster and more efficient breakdown of organic material, increased biogas yields, and a reduced likelihood of pathogen survival (Cavinato et al., 2010).

Importantly, Denmark's successes have been fueled by a comprehensive policy framework that sets targets for biogas utilization and funds the development and installation of new technologies to improve the efficiency of on-farm anaerobic digestion (Jacobsen, 2011). In terms of their biogas production, there are multiple major biogas plants in Denmark, including Maabjerg BioEnergy. This bioenergy plant processes up to 500,000 tons of solid and liquid manure from local farms annually and uses the remaining digestate to produce compost, representing a closed-loop system (no waste outputs). This plant is economically viable due in large part to early-stage government capital funds for the building of digesters and similar infrastructure, highlighting the need for such support to replicate this case study elsewhere (IEA, 2014).

3) Composting is an aerobic process where organic material is decomposed by microorganisms in the presence of oxygen. Properly managed composting reduces methane emissions since methane-producing anaerobic conditions are avoided. There are a variety of benefits to managing methane emissions through composting. This manure management strategy reduces methane emissions, provides a stable organic fertilizer, and reduces the volume and weight of manure, making it easier to handle and transport (Czekała et al., 2023).

Potential issues:

These manure management solutions, however, also come with challenges. The initial investment required for the necessary infrastructure is substantial and can be a significant barrier for farmers. Moreover, maintaining and monitoring the anaerobic digestion process demands continuous labor, increasing operational costs. These factors can impact the overall cost-effectiveness and benefits for farmers, making it essential to consider financial incentives or support mechanisms to encourage adoption (US EPA, 2022). Additionally, even at 100% effectiveness, manure management solutions will only cover about 5% of methane emissions from cattle, making the impact for real environmental benefits low (Song et al., 2023).

05. Issues and controversies

ISSUES AND CONTROVERSIES

5.1 Overarching Issues and Controversies

In addition to the caveats outlined above for each particular solution, there are four major issues affecting the implementation of all solutions. First, the research is still in its early stages, making it essential to establish consistent and standardized methods for measuring emissions, ranging from single animals to entire farms (Króliczewska et al., 2023; Tseten et al., 2022). This consistency and standardization are necessary to ensure reliable comparisons between studies, as widely used measurement techniques will provide a solid foundation for evaluating and comparing the effectiveness of various mitigation strategies across different contexts (de Haas et al., 2021). For that reason, it is essential for emissions measurement standards to be agreed upon and adhered to by the national or, preferably, international scientific community, funders, and governments.

Additionally, the cost of animal studies often leads to small sample sizes and varied results (Henderson et al., 2015). Increasing sample sizes is crucial for obtaining accurate findings. Larger and more diverse studies will enhance the reliability of the data, allowing for more robust conclusions and better-informed policy decisions (de Haas et al., 2021).

Furthermore, much of the early research has been limited to in vitro experiments (those conducted outside of a living organism, i.e. in a petri dish or test tube). To gather practical results, it is important to apply these solutions in real-life situations (Cristobal-Carballo et al., 2021). Conducting in vivo research (conducted in a living organism, i.e. in live cattle subjects) and long-term studies across different environments will provide practical insights and validate the efficacy of proposed solutions under real-world conditions (Gerber et al., 2013; Henderson et al., 2015).

Finally, farmers need to at least break even and ideally profit from adopting new practices to incentivize them to comply with new practices. While reducing methane emissions benefits society as a whole, it often doesn't directly benefit individual farmers. Implementing these solutions can be costly, so solutions must either be funded by the USDA or designed to enhance production and animal health while reducing methane, creating a win-win scenario (de Haas et al., 2021). Financial incentives are crucial to encourage farmers to adopt methane reduction practices. Solutions that offer economic benefits, such as improved animal health or productivity, alongside environmental benefits, will be more likely to gain widespread acceptance (Gerber et al., 2013).

06. Measuring Success

MEASURING SUCCESS

Measuring success is essential for assessing the performance of a government program. It provides a clear understanding of current effectiveness and informs the development of strategies for improvement. When managing the implementation of the EMIT-LESS Act of 2024, the USDA will need to evaluate its success. While the bill contains three major elements, measuring success will occur at two different levels: first, measuring the success of the research into methane-reducing solutions from enteric fermentation and manure, and second, measuring success of the implementation of the government program itself. For this purpose, the measurement techniques that can facilitate research and surveillance of the program as outlined in the bill must be identified and indicators that the USDA can use to monitor progress and enhance program administration must be defined. It is important to develop standardized measurements to increase comparability of different approaches and ensure reliability of results.

To measure the success of methane-reducing research and program implementation, a variety of measurement techniques must be used. This includes animal-level measurements, which focus on individual cattle, and land-based measurements, which assess manure storage facilities, groups of cattle, or entire farms (Figure 6) (National Academies of Sciences, Engineering, and Medicine et al., 2018; Zhao et al., 2020).

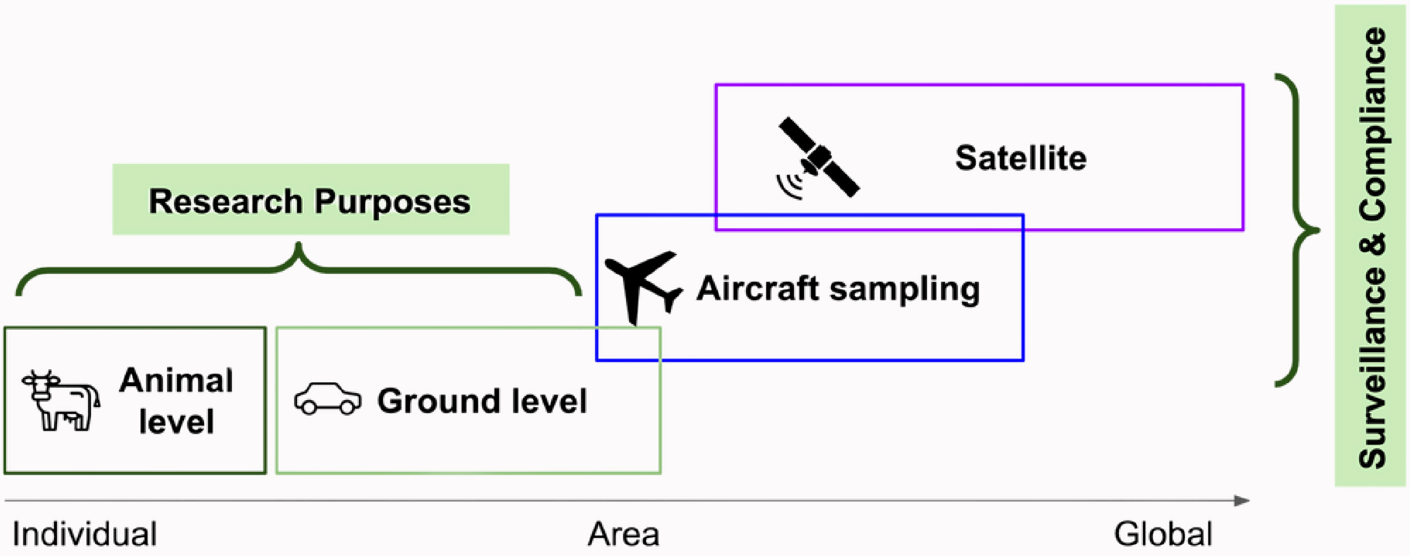


Figure 6: Methods for measuring methane emissions, source: Adapted from National Academies of Sciences, Engineering, and Medicine et al. (2018)

6.1. Animal-level measurements

There are three main techniques used to measure enteric methane emissions at the animal level, respiration chambers, sulfur hexafluoride (SF6), and the GreenFeed monitoring system (Starsmore et al., 2024).

Respiration Chambers: Respiration chambers are a precise method of measuring enteric methane emissions for research purposes, where animals are usually confined for 2 to 4 days. The head of the animal is placed into an enclosed chamber and methane emissions are calculated based on the gas flow and the differences in gas concentrations between the air inlet and outlet (Huhtanen et al., 2015). This method has relatively high investment and labor costs, with a rather difficult set-up process (Huhtanen et al., 2015). This makes it unsuitable for large scale studies with hundreds of cattle.

Sulfur Hexafluoride Tracer Technique: The sulfur hexafluoride (SF6) tracer method is a way to measure methane emissions from confined or grazing ruminants. This involves placing a small tube filled with SF6, the tracer gas, inside the cattle's rumen, where it releases SF6 at a known and steady rate. A special halter then collects the animal's exhaled gasses into a container, which is later analyzed to determine the concentrations of both methane and the SF6. By analyzing these concentrations and accounting for various factors using the tracer gas, researchers can calculate the methane emissions from the animal (Zhao et al., 2020). This method is less expensive than respiration chambers and is especially useful for large-scale studies that want to consider confined and grazing animals. However, its accuracy in measuring methane emissions has been challenged in multiple studies (Hammond et al., 2015).

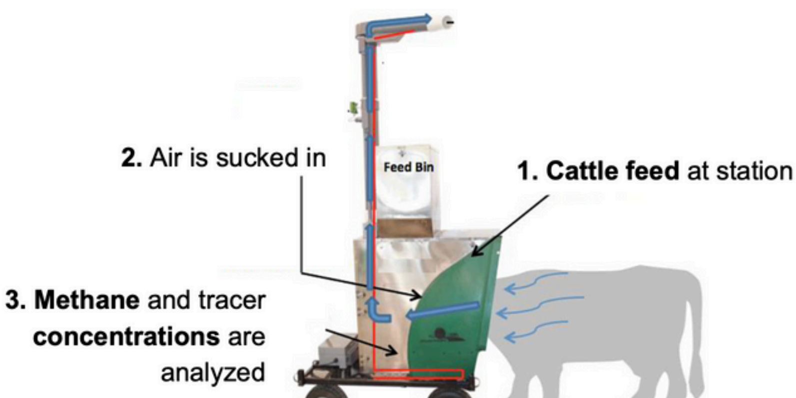


Figure 7: Conceptual representation of the GreenFeed Monitor (© C-Lock), source: Adapted from Cabezas-Garcia (2017)

GreenFeed Monitoring: GreenFeed Monitoring (Figure 7) modifies the classic respiration chamber technique. It was developed by the company C-Lock and allows for the measurement of methane emissions from animals in their natural, i.e., usual, setting (C-Lock Inc., n.d.). In this system, animals are attracted to a feed trough by food, prompting them to voluntarily place. their heads inside. The system then draws air from around the animal's nose and mouth into a duct, where the concentrations of respired or burped gasses are measured over time. This setup allows for the determination of methane emissions and other gasses like hydrogen (Zhao et al., 2020). The method is relatively cheap, has high accuracy, and easy for farmers to implement on a larger scale (Starsmore et al., 2024).

6.2. Land-based measurements

There are several land-based measurement methods. For the purpose of the EMIT-LESS bill, the following three will be examined: ground measurements, flyover measurements and satellite measurements.

Ground Measurements: Ground measurements can be done using either a tracer gas (Figure 8) or infrared spectrometry. The tracer method is typically used for research purposes, as it requires the setup of equipment next to the farm and therefore the permission of the landowner. For this purpose, the tracer gas, such as acetylene or nitrous oxide, is released at a known rate at the source area, e.g., a manure storage container. Both the methane and the tracer gas concentrations are then measured either across downwind plumes or from a mobile vehicle, like a car, to derive the methane emission rate (National Academies of Sciences, Engineering, and Medicine et al., 2018). This method is accurate and relatively easy to set up, but it might become expensive for extended studies and might be difficult to scale since landowner approval is always required (Vechi & Scheutz, 2023). An alternative method that doesn't necessarily require landowner permission is to measure methane emissions from towers using infrared spectrometry at precise infrared wavelengths. The concentrations can then be analyzed by applying eddy covariance or inverse modeling to the time series (National Academies of Sciences, Engineering, and Medicine et al., 2018). Eddy covariance uses wind speed and methane emissions to directly measure net gas exchange over an area while inverse modeling indirectly infers the spatial and temporal distribution of gas sources (Kowalska et al., 2013; National Academies of Sciences, Engineering, and Medicine et al., 2018). This method is highly accurate but not easy to scale because many towers would be necessary and it is expensive to set them up, relative to the range that they cover (National Academies of Sciences, Engineering, and Medicine et al., 2018).

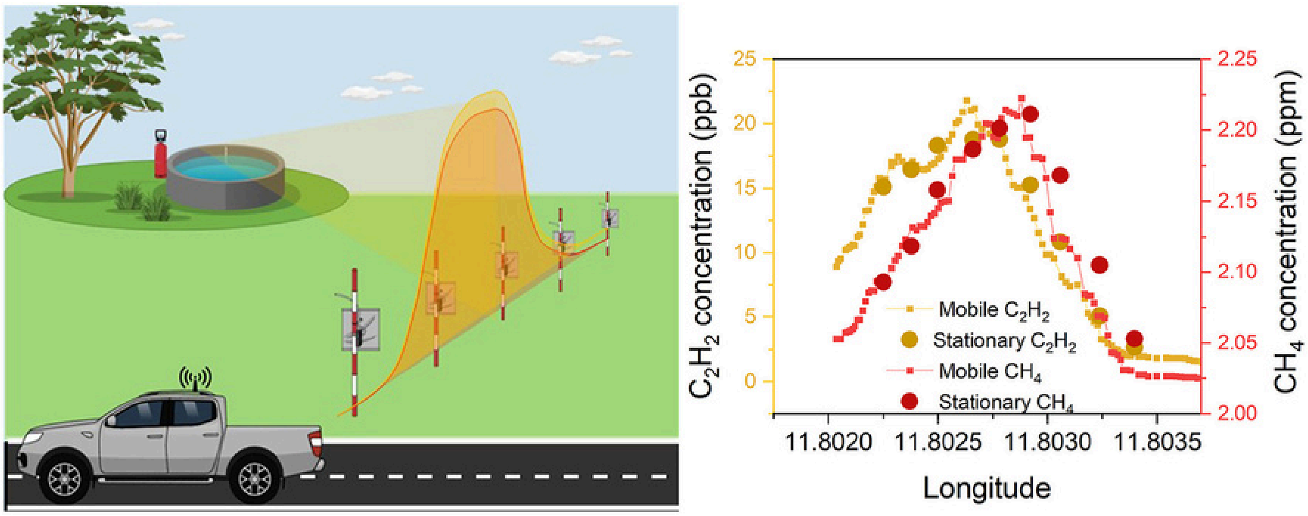


Figure 8: Visual representation of a ground measurement technique, source: Vechi & Scheutz (2023)

Flyover Measurements: Aircraft measurements cover a wider range than ground measurements and can be used for both individual and multiple clustered facilities (farms). Similar to ground measurements, aircraft measurements can be done using either a tracer gas or spectrometry. When using the tracer method, the methane emission rate is derived from multiple vertical measurements of atmospheric methane and wind-speed gradients above the source area (Daube et al., 2023; National Academies of Sciences, Engineering, and Medicine et al., 2018). This method is relatively accurate but expensive and difficult to scale, while also requiring landowner approval because the aircraft has to fly very low. This makes it mostly suitable for research purposes (National Academies of Sciences, Engineering, and Medicine et al., 2018). Aircraft remote sensing measurements apply absorption spectroscopy using reflected sunlight or thermal emission to map methane concentrations (National Academies of Sciences, Engineering, and Medicine et al., 2018). This method is more expensive and has limited scalability, which is why it is mostly used in conjunction with other methods and to test spectroscopy measurements for satellite measurements (Environmental Defense Fund, n.d.).

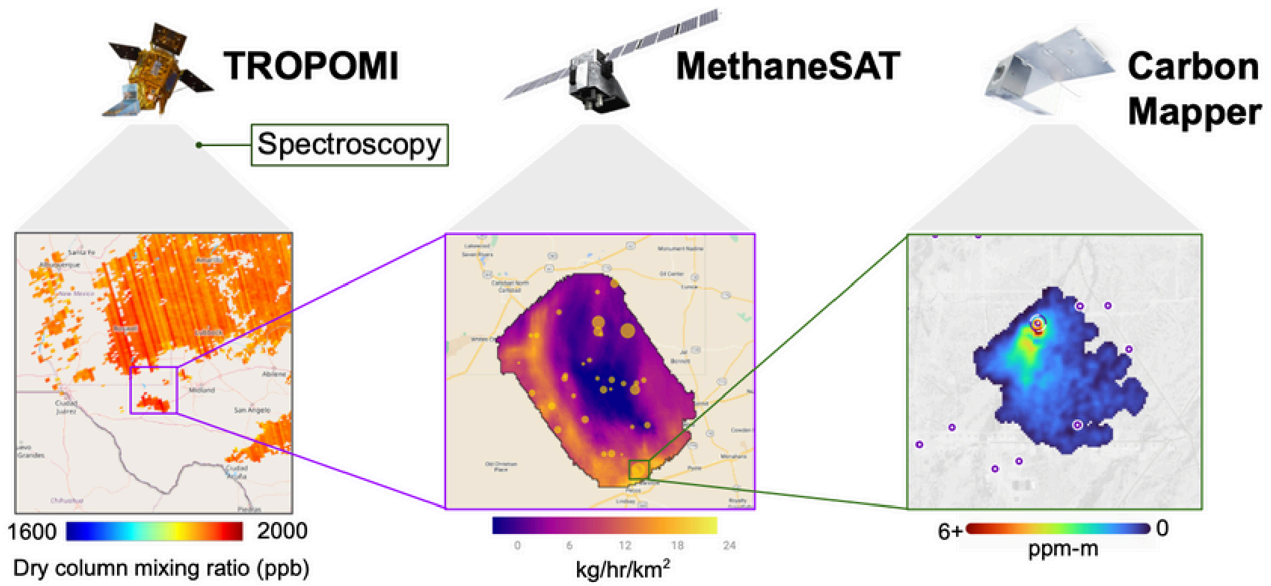


Figure 9: Conceptual representation of using satellites collaboratively, source: Carbon Mapper (n.d.), KNMI (2023); MethaneSAT (2024)

Satellite Measurements: Satellite measurements (Figure 9) are already in use and are continuously being developed further by various intergovernmental organizations, companies, and nonprofits. Similar to other land-based techniques, they use absorption spectroscopy to derive methane concentrations from reflected sunlight or thermal emissions (National Academies of Sciences, Engineering, and Medicine et al., 2018). However, all satellites have a certain range of spatial resolution and therefore need to work together to create a complete and accurate picture of methane emissions. There are several satellites in orbit, but for illustration purposes, we will limit ourselves to TROPOMI, MethaneSAT, and CarbonMapper (Figure 9) (Carbon Mapper, n.d.; MethaneSAT, 2024; TROPOMI, 2024). For example, TROPOMI, a satellite developed by the European Space Agency (ESA), is designed to provide a broad view of large areas, identifying regions with high emissions with an accuracy of 7,000 m x 5,500 m. MethaneSAT, developed by the Environmental Defense Fund in collaboration with a consortium of other organizations, zooms in on these regions to identify smaller areas of high emissions with an accuracy of 100 m x 400 m pixels. Finally, satellites like CarbonMapper, developed by CarbonMapper, can focus on specific sites to pinpoint the exact sources of methane with an accuracy of 30 m x 30 m pixels (MethaneSAT, 2024). While using satellites is expensive, they can achieve very high accuracy and enable global scalability when combined.

For the first part of the EMIT-LESS bill, which involves research funding and improving methane-reducing solutions, the various solutions must be paired with the measurement technique that best suits their nature. Solutions are classified into three categories: feed management, advanced solutions, and manure management. Feed management includes all solutions that change the animal's diet to reduce enteric methane emissions (e.g., altering diet, using feed additives, and implementing early life/fetal interventions). Because these solutions impact individual animals, their effectiveness is best measured at the animal level, for instance, using the GreenFeed chamber. The second category, advanced solutions, includes selective breeding, genetic manipulations, and vaccines. Since these solutions also target methane emission reductions in individual animals, they are best measured using the GreenFeed monitor or other animal-level measurements. Lastly, manure management solutions focus on reducing methane emissions from stored manure. Consequently, land-based measurements, most likely ground measurements, are the most appropriate for these solutions.

Aircraft and-to a larger extent-satellite measurements will be used not for the first part of the bill, research, but rather for the second part of the bill, monitoring and enforcement. This means that those techniques could monitor whether farmers are actually reducing emissions after receiving payments for implementation or determine who the largest emitters in the country are. This would allow the USDA to optimize its outreach and efforts to reduce methane emissions.

6.3 Direct Indicators to Measure Success

The main goal of the EMIT-LESS bill is to reduce methane emissions from cattle facilities. Therefore, the main direct indicator of success is the reduction of methane from cattle, i.e., enteric methane as well as methane from manure. While this could be done using global satellite measurements, for the purpose of the bill and how the USDA manages its implementation within the next two to five years, this indicator is unlikely to be helpful and might not show significant progress despite much effort. Therefore, governments typically derive indirect indicators that they can use to actively manage their programs (Berten, 2022).

6.4 Indirect Indicators to Measure Success

The following indirect indicators should be used to measure the success in the three different areas of the bill:

1. Research Funding

Indicator	Rationale
Number of research facilities funded	To measure potential research output
Volume of baseline data collected	To determine where the US is currently standing
Volume of research funded through USDA and independent research universities and institutions	To measure rollout of research funding
Numbers of articles published in peer-reviewed journals on methane emissions reduction, animal productivity, and animal health as a result of funding by the EMIT-LESS Act	To measure whether funded research is actually producing publishable results in peer reviewed journals

2. Training Programs Funding

Indicator	Rationale
Number of training programs established or expanded	To measure potential research output
Number of educational institutions participating	To determine where the US is currently standing

2. Training Programs Funding *(continued)*

Indicator	Rationale
Balance of participants with regards to gender, race, and socioeconomic background	To measure rollout of research funding
Average knowledge gain pre- and post-training measured through surveys	To measure whether funded research is actually producing publishable results in peer reviewed journals
Adoption rate of mitigation practices after going through training	To measure practical effectiveness of training program and whether they result in farmers adopting solutions

3. Payment Programs

Indicator	Rationale
Volume of payments to farmers for implementing methane reduction solutions	To determine how many farmers are planning and implementing solutions
Number of farmers receiving payments for implementing methane reduction solutions	To determine whether few large farmers or many smaller farmers implement solutions (or a combination of both)
Balance of recipients of payments with regards to gender, race, and socioeconomic background	To determine whether the payment program is equitable and whether government efforts within certain groups have to be increased
Average reduction of enteric methane emissions per participating farmer	To measure whether implementation of solutions actually reduces methane emissions at the animal level

07. Conclusion

The Enteric Methane Innovation Tools for Lower Emissions and Sustainable Stock (EMIT-LESS) Act (S. 4056) represents a comprehensive and future-oriented effort to address the significant environmental challenges posed by methane emissions.

By focusing on research, training of farmers, and financial incentives the Act not only reduces enteric methane emissions from cattle but also promotes sustainable farming practices that benefit animal, farmers, consumers, and the environment.

The success of this effort will depend on the Act's implementation, the participation of research facilities, academic institutions, and farmers, and the continuous monitoring of its progress and impact.

By incentivizing the participation of several stakeholders, the EMIT-LESS Act has the potential to make a substantial contribution to the mitigation of climate change and ensure a shift to sustainable livestock management within the livestock industry.

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