Environmental Defense Fund

CARBON LIMITS



CARBON CREDITS FOR LIVESTOCK METHANE REDUCTIONS:

Making sense of compliance and voluntary offset methodologies

Authors

Environmental Defense Fund

Amy Hughes; Erin Leonard; Joe Rudek; Peri Rosenstein; Maggie Monast

One of the world's leading international nonprofit organizations, Environmental Defense Fund (EDF) creates transformational solutions to the most serious environmental problems. To do so, EDF links science, economics, law and innovative private sector partnerships. With more than 2.5 million members and offices in the United States, China, Mexico, Indonesia and the European Union, EDF's scientists, economists, attorneys and policy experts are working in 28 countries to turn our solutions into action.

CARBON LIMITS

François Sammut; Irina Ålund; Laura Camila Cruz; Vladyslav Zhezherin; Irina Semykina

Carbon Limits works with public authorities, private companies, finance institutions and non-governmental organizations to reduce greenhouse gas emissions from a range of sectors. Our team supports clients in the identification, development and financing of projects that mitigate climate change and generate economic value, in addition to providing advice on the design and implementation of climate and energy policies and regulations.

Acknowledgments

John Tauzel; Holly Pearen; Vrashabh Kapate; Fiona Kurylowicz; Mindi DePaola; Jennifer Bockhahn; Kevin Ogorzalek

PUBLISHED SEPTEMBER 2024

Table of Contents

Executive Summary 1

Introduction 12

Carbon Credit Market Process, Governance and Quality 15

Crediting Methodologies for Reducing Livestock Methane Emissions 22

Reduced Enteric Methane Emissions Methodologies 24

Avoided Manure Methane Emissions Methodologies 29

Determining the Emissions Impact of Avoided Livestock Methane Emissions Activity 32

Additionality 34

Permanence 37

Robust Quantification of Emissions Reductions and Removals 38

Sustainable Development Benefits and Safeguards 68

Recommendations 79

Scientific Community 84

Accrediting and Governance Bodies 87

Appendix: Summary of Assessment Against Specified Criteria 88

Endnotes 96

Executive Summary



Livestock production systems are both an important source of global livelihoods and nutrition and a significant contributor to climate change. Total greenhouse gas emissions (GHGs) from global livestock come to 7.1 gigatonnes of carbon dioxide equivalent (CO_2e) using a 100-year global warming potential (CO_2e GWP 100) per year, about half of which is methane; this represents over 14% of all anthropogenic GHG emissions.[1] Methane (CH_4) is a short-lived climate pollutant, having more than 80 times the warming power of carbon dioxide (CO_2) in the first 20 years.[2] Even though CO_2 has a longer-lasting effect, methane sets the pace for warming in the near term. Reducing global methane emissions by at least 30% from 2020 levels by 2030 is one of the fastest ways to slow global warming by mid-century.[3]

CO_2 equivalents used in this report are based on 100-year GWPs (or GWP-100) from the Intergovernmental Panel on Climate Change's Fourth Assessment report, unless indicated otherwise. GWP is a measure of the relative influence of a unit (e.g., 1 kg) of a GHG on global temperature within a given time horizon, which can be a 100-year or 20-year period (EPA 2020). Expressing non-CO_2 GHGs as CO_2e involves weighing gases by their GWP, in comparison to that of CO_2. The GWP for methane over a 20-year time period is about three times greater than when considered over a 100-year time period.

Reducing methane emissions from energy, agriculture and waste is a critical part of avoiding the worst consequences of climate change.

There are various existing technologies and livestock management practices that can effectively contribute to reducing methane emissions from livestock production systems.

There is an urgent need to mobilize capital to livestock operations globally to invest in solutions that will effectively address these emissions. One way to achieve this is through voluntary and compliance-based carbon markets that adhere to science-based quantification and accounting principles to generate, account for and trade emissions reductions. Carbon crediting programs are increasingly focused on mitigating the impact of livestock production on climate change. More carbon market credits are being generated and purchased each year, and there is an opportunity to leverage this growth to drive investments in lowering methane emissions from livestock production.[4]

This report provides a global overview of 25 active or draft carbon crediting methodologies governed by 11 unique organizations and governments, which quantify and certify reduced and avoided GHG emissions from livestock systems. Through their carbon crediting methodologies, these crediting systems set the requirements and standards to ensure that livestock emissions reductions are real and high quality. They outline the procedures and methods for implementing, measuring, monitoring, reporting and verifying project activities which need to be followed to generate carbon credits. More specifically, these crediting methodologies primarily include methane emissions from dairy, beef and swine operations and sometimes include poultry and other ruminants such as buffalo and goats. Some of the methodologies address emissions reductions resulting from improved manure management and some address various strategies for reducing emissions from enteric fermentation.[5]

Enteric fermentation is a natural part of the digestive process in ruminant animals such as cattle, sheep, goats and buffalo. Microbes in the digestive tract, or rumen, decompose and ferment food, producing methane as a by-product.

In addition, this report summarizes five national and regional U.S. government methodologies, four Canadian government methodologies, four Australian government methodologies, and 11 from international organizations and standardization bodies, including the United Nations Clean Development Mechanism, Gold Standard and Verra.[6]

While the UN CDM registry is no longer accepting new projects, UN CDM methodologies can be used to register projects in the voluntary carbon market, such as under the Verra VCS and Gold Standard registries, which is the basis for the inclusion of these methodologies in our review.

These methodologies are tailored for use across the following types of carbon marketplaces:

- Voluntary carbon markets selling carbon credits to corporate buyers outside of food and agriculture value chains who are offsetting some of their difficult-to-abate emissions as part of an overall net-zero emissions strategy.
- Compliance carbon markets regulated by mandatory national, regional or international carbon reduction organizations.
- National and sub-national level regulations designed to decrease the carbon intensity of transportation fuel pools by incentivizing a range of low-carbon and renewable alternatives, including livestock manure-produced biogas that contains methane.

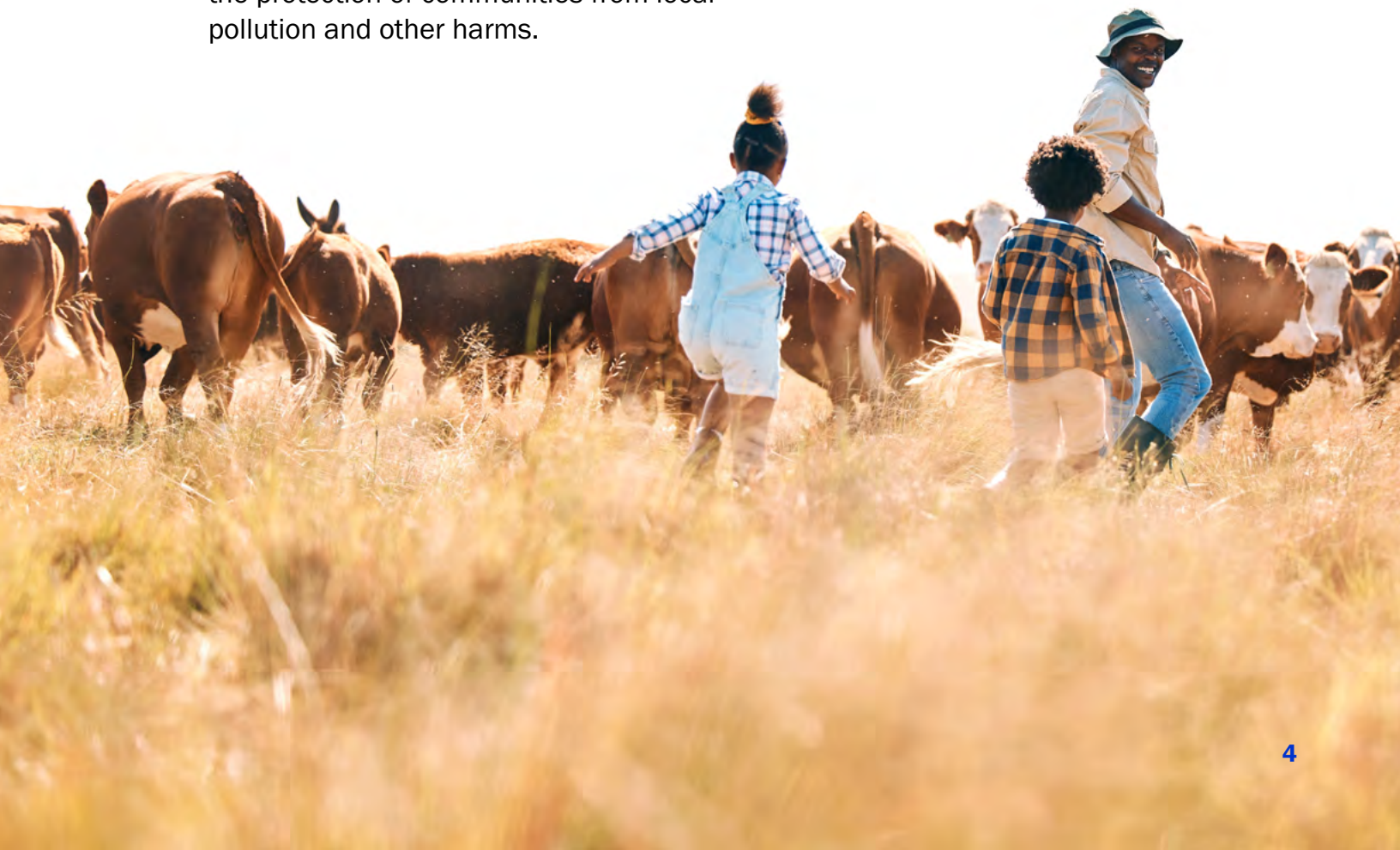
Robust quantification of emissions reductions is fundamental to carbon market integrity and is dependent on effectively determining baseline emissions levels and measuring, monitoring, reporting and verifying (MMRV) avoided and reduced emissions beyond the business-as-usual scenario. The reputation of, and confidence in, any carbon crediting program, along with associated methodologies, rests largely on the robust determination of emissions impact.

In addition, it is critical that carbon crediting programs prioritize both equity and environmental justice.

Programs should have sufficient sustainable development benefits and safeguards that provide equitable opportunities for smallholder livestock operations to participate as well as ensure the protection of communities from local pollution and other harms.

This report assesses how each methodology addresses four of the 10 Core Carbon Principles (CCPs) established by the Integrity Council for the Voluntary Carbon Market (ICVCM), a multi-stakeholder-led independent governance body that establishes and maintains the highest standards of ethics, sustainability and transparency for the global voluntary carbon market.[7] The CCPs establish a global benchmark for high-integrity carbon credits through the issuance of a CCP label to qualifying methodologies.[8]

All 10 core carbon principles can be found here: icvcm.org/core-carbon-principles



The subset of four principles and corresponding criteria were selected for this analysis as they best represent characteristics important to livestock methane emissions reductions. Given that only four of the 10 CCPs were analyzed, this report should not be considered exhaustive.

ICVCM CORE CARBON PRINCIPLES CONSIDERED IN THIS REPORT

Core Carbon Principle	Description
Methodology-level: *Emissions Impact* — Additionality	Emissions reductions or removals from the mitigation activity shall be additional, i.e., they would not have occurred in the absence of the incentive created by carbon credit revenues.
Methodology-level: *Emissions Impact* — Permanence	The GHG emissions reductions or removals from the mitigation activity shall be permanent or, where there is a risk of reversal, there shall be measures in place to address those risks and compensate reversals.
Methodology-level: *Emissions Impact* — Robust quantification of emissions reductions and removals	The GHG emissions reductions or removals from the mitigation activity shall be robustly quantified, based on conservative approaches, completeness and best available scientific methods that take into account uncertainty associated with models and emissions factors used. Key criteria include: • Accounting for all significant sources and sinks • Setting an appropriate baseline • Comparable quantitative methods for baseline and mitigation activity emissions • Considering and minimizing leakage • Crediting periods appropriate to the type of mitigation activity • Conservative use of default values and appropriate discounting to address uncertainty.
Program-level: Sustainable development benefits and safeguards	The carbon-crediting program shall have clear guidance, tools and compliance procedures to ensure mitigation activities conform with or go beyond widely established industry best practices on social and environmental safeguards while delivering positive sustainable development impacts.

While the establishment of the CCP criteria is a major step forward for the voluntary carbon market, the ability to most accurately quantify, monitor, report and verify emissions reductions is constantly evolving based on scientific and technological advances. The CCP label represents the minimum viable threshold for a quality credit; however, there are still improvements that can be made to methodologies in the livestock space to go above and beyond the quality criteria and to continually improve the accuracy and impact of credits issued for these credit types.

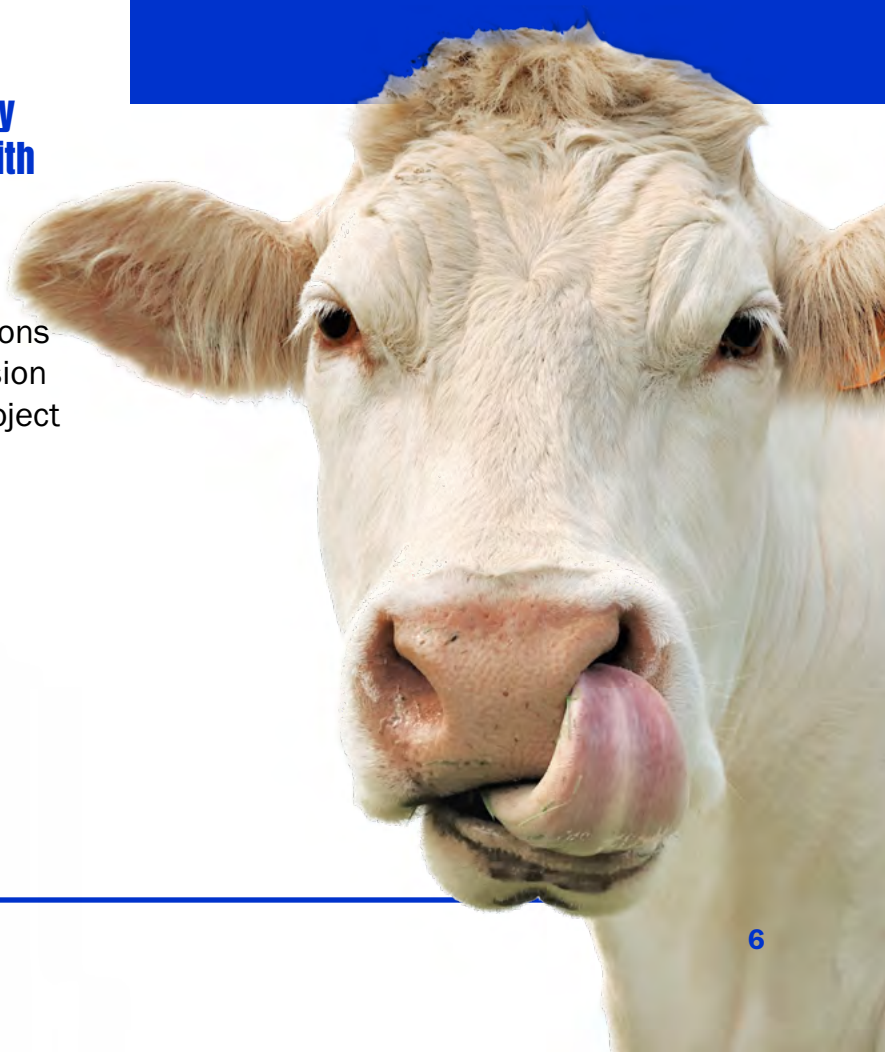
Voluntary and compliance carbon markets are a source of much-needed finance to help the agriculture sector realize its potential for climate mitigation.

There is a need for the scientific community and carbon registries to actively collaborate to regularly update existing methodologies with the best available science.

The variety of distinct crediting methodologies for livestock emissions reductions may also lead to confusion and reticence on behalf of both project developers and buyers of carbon credits.

This report aims to illuminate the quality of livestock crediting methodologies by providing a high-level assessment of the current methodologies and mechanisms and their key differences. The analysis finds:

- All of the methodologies assessed in this report have language and processes that consider each of the four criteria reviewed (i.e., all methodologies take into account additionality, permanence, emissions impact and social safeguards).
- There is notable variance in how each criterion is addressed and monitored across methodologies; there is no standard approach to addressing any of the four criteria.



Methodology approaches to the quality criteria assessed are summarized in tables across this report and in the appendix. Across the four criteria, our report found that:



Additionality: The relatively low adoption of methane reduction technologies along with the upfront and ongoing investment needed in order for farming operations to adopt these technologies means that funding for livestock projects can indeed drive emissions reductions that would not have happened otherwise and therefore there is generally strong additionality of credits generated from livestock methane reduction. Analysis of project additionality is generally sufficient across methodologies.



Permanence: Credits generated from livestock methane reduction projects represent permanent emissions reductions without risk of reversal and therefore this criteria is sufficiently addressed across methodologies.



Emissions impact: All methodologies assessed define a project boundary and provide sufficient quantification methodologies to calculate baseline and project emissions. While all methodologies assessed meet the requirements for this quality criteria, crediting programs could go further to improve credit integrity as it relates to this criteria. Furthermore:

- Regarding the quantification of project emissions impact, there is a high reliance on emissions factors and models across methodologies; therefore, the quality of those emissions factors and models is very important for accurate accounting and overall credit integrity.
- Variance across crediting programs' quantification methodologies (such as using different default values for the same parameters) creates a risk of generating credits that are not equivalent or even comparable.



Sustainable development benefits and safeguards: While most methodologies consider some type of social and environmental safeguards as part of the project requirements, they are often determined at the program level rather than the project level, and often defer to local regulation as a proxy for meeting this requirement. Environmental and social safeguard standards are rarely tailored to livestock-specific projects. Crediting programs could take action to increase credit integrity as it relates to these criteria.

This report also highlights where there are currently opportunities for crediting programs, standards bodies and the scientific community to contribute to improving the robust quantification of emissions and social benefits and safeguards. Opportunities for improvement include:

Undertake research to provide higher quality, lower uncertainty emissions reduction default values to more accurately quantify projects' emissions impacts for both enteric and manure methodologies.

Quantification uncertainty leads to a possible risk of over- or under-estimation of credits generated. There are opportunities to increase the quality of parameters used to estimate emissions and emissions reductions, as well as provide a level of granularity reflecting the diversity of conditions and operating practices found at national or regional levels; such as feed quality, typical diets, animal life stage, breed, average climatic conditions and animal stress. Doing so requires continued investment in high-quality peer-reviewed research and strong systems for governing bodies and crediting programs to review and update methodologies with the best available research.

Establish guidelines and best practices for assessing the applicability of scientific evidence for the safety and efficacy of feed additives in the project setting and to ensure that quantification methodologies are regularly updated as additional data becomes available.

Many studies using feed additives for the desired outcome of enteric methane reduction have been conducted under various conditions and with varying results, some showing promising reductions in enteric methane emissions. However, there are critical unknowns regarding the safety and efficacy of these solutions in real-world settings. There are significant challenges for accurately quantifying emissions reductions at the project level. Supporting further research and education on feed additives and other interventions for enteric methane reduction to demonstrate their safety for animal and human health and their efficacy under different livestock management systems and over longer study durations can help support this goal.

Fill research gaps related to full GHG accounting for manure management projects, especially for manure digester projects.

Currently, there are gaps in scientific understanding of methane leakage, nitrous oxide (N2O) emissions and ammonia emissions with the use of manure management systems. For digesters, understanding levels of leakage throughout the biogas upgrading system is critical to accurately accounting for emissions reductions. Additionally, further research into ammonia and N2O emissions from the digestate is needed to understand the true net benefits of digester technologies; ammonia emissions impact local environments and health and both ammonia and N2O emissions have negative global impacts so understanding the full picture is important for this project type.

Institute and/or strengthen program requirements aimed at protecting local communities, going beyond regulatory requirements where needed.

Climate mitigation projects do not always seek to reduce co-pollutants at the emissions source, and these co-pollutants can be a major source of local air pollution and human health impacts. In addition to air quality, issues with odor and water quality can also be of great concern to communities with livestock operations as neighbors.

Many methodologies accept project adherence to local regulations as sufficient criteria for project eligibility. Still, in the case of local pollution, human food safety and animal safety, local regulation enforcement may not always be sufficient and can vary between jurisdictions.[9] Carbon-crediting programs should explore how their environmental and social safeguard standards can be tailored to livestock-specific projects and go beyond local regulatory requirements where needed to ensure that local communities benefit from carbon projects.

Ensure that governance, accreditation, standards and rating bodies active in the voluntary carbon market implement robust processes for updating criteria to reflect the best available science and take into account livestock-specific considerations for criteria related to emissions quantification, project eligibility, and environmental and community safeguards.

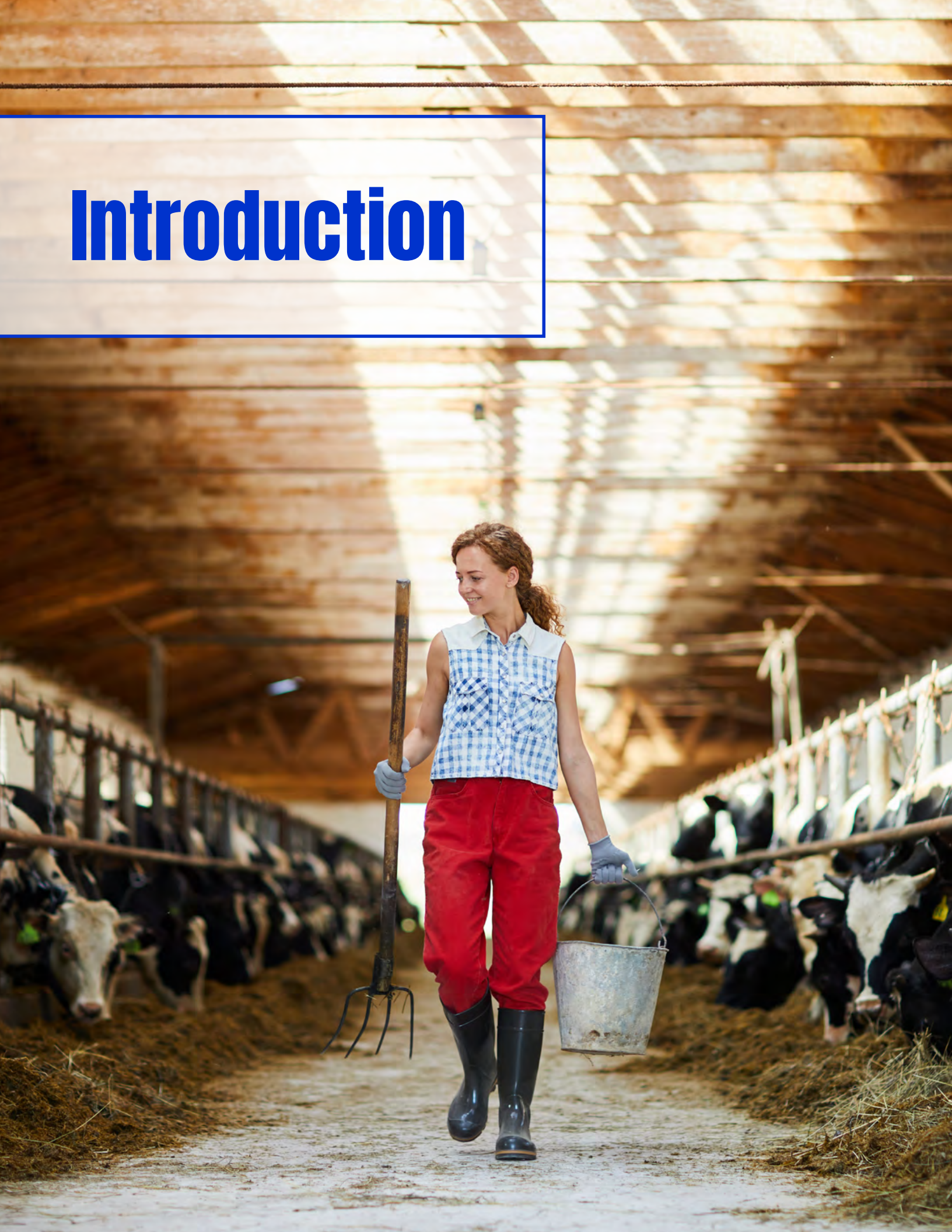
Strong systems for crediting programs to review and update methodologies with the best available research are paramount to ensuring continuous improvement at the program level and continuing to build trust in the voluntary carbon market as a whole. Doing so can be an important pathway to driving the adoption of the recommendations outlined above.



ABBREVIATIONS AND ACRONYMS

ACR	American Carbon Registry
CAR	Climate Action Reserve
CARB	California Air Resources Board
CCP	Core Carbon Principle
CCQI	Carbon Credit Quality Initiative
CDM	Clean Development Mechanism
EDF	Environmental Defense Fund
EF	Emissions factor
EPA	Environmental Protection Agency
ERF	Emissions Reduction Factor
ETS	Emissions Trading System
GHG	Greenhouse gas
GHGP	Greenhouse gas protocol
GS	Gold Standard
GWP	Global warming potential
ICVCM	Integrity Council for the Voluntary Carbon Market
IPCC	Intergovernmental Panel on Climate Change
LCFS	California Low Carbon Fuel Standard
MCF	Annual methane conversion factor
MMRV	Measuring, monitoring, reporting and verification
NGO	Non-governmental organization
PoA	Programme of Activities
RFS	Renewable fuel standard
RGGI	U.S. Regional Greenhouse Gas Initiative
UNFCCC	United Nations Framework Convention on Climate Change
U.S. EPA	U.S. Environmental Protection Agency
VCMI	Voluntary Carbon Markets Integrity Initiative
VCS	Verified carbon standard

Introduction



While livestock production systems are an important source of both global livelihoods and nutrition, they are also a significant source of anthropogenic methane (CH_4) emissions, which are currently rising at a faster rate than ever recorded previously.[10] This potent gas has more than 80 times the warming power of carbon dioxide (CO_2) over the first 20 years after it reaches the atmosphere.[11] Even though CO_2 has a longer-lasting effect, methane sets the pace for warming in the near term, providing a critical opportunity to reduce the rate of warming over the next few decades. Globally, livestock production contributes roughly one-third of anthropogenic methane emissions, with the largest contribution being enteric emissions.[12] Rapid action to reduce methane emissions is one of the fastest ways to slow global warming in the near term and a critical part of avoiding the worst consequences of climate change.

According to the Food and Agriculture Organization of the United Nations (U.N.):[13]

39% of total global emissions from agriculture come from methane emissions resulting from enteric fermentation in ruminants[14]

10% 10% of total global emissions from agriculture come from methane and N_2O emissions resulting from manure management



Other sources of GHGs include emissions from feed production and processing, and the processing and transportation of animal products

Reducing emissions from enteric fermentation and livestock manure management is key to reducing overall methane emissions, but existing technologies to achieve these goals require significant capital investments and ongoing operational expenses. Current strategies and technologies available to reduce methane from livestock do not provide farmers with a return from increased animal productivity or on-farm cost savings significant enough to offset the upfront investment; therefore, additional financing is needed. Carbon markets are one potential mechanism to mobilize capital and scale the necessary technologies and solutions to reduce methane emissions from livestock systems. While financing can come from a variety of sources, the demand for carbon offset credits is growing which presents an opportunity to rapidly mobilize capital for the upfront financing needed for these solutions.

Existing methodologies are aimed at two types of reductions: enteric methane emissions reductions and livestock manure management emissions reductions.

Credits for reductions from both enteric and manure management emissions are considered ***avoided emissions***, meaning they result from an action that reduces or entirely prevents the emissions that would have otherwise happened without the incentive of the crediting activity. This report uses the terms “avoided” and “reduced” emissions interchangeably.

Enteric fermentation is a natural part of the digestive process in ruminant animals such as cattle, sheep, goats and buffalo. Microbes in the digestive tract, or rumen, decompose and ferment food, producing methane as a by-product.

Avoided emissions from livestock projects are ***permanent*** emissions reductions, meaning that the emissions reduced cannot be reversed and put back into the atmosphere after the fact. Furthermore, the relatively low adoption of methane reduction technologies, along with the upfront and ongoing investment needed in order for farming operations to adopt these technologies, means that funding for livestock projects can indeed drive emissions reductions that would not have happened otherwise and are therefore ***additional*** to the baseline. Additionality and permanence are two of the Core Carbon Principles and two features of this credit type that could make it attractive to buyers.



CARBON CREDIT MARKET PROCESS, GOVERNANCE AND QUALITY

Emissions trading programs (or carbon markets) cap and cut climate pollution through market-based mechanisms that put a price on GHG reductions either via regulatory or voluntary ***markets***. Carbon offset credits are generated when an entity reduces or captures carbon and verifies the carbon impact of the intervention via a carbon registry that facilitates the sale of the credit to a buyer to offset a portion of their existing emissions. The ***quality*** or ***integrity*** of a credit refers generally to the level of confidence that those participating in the market can have that a credit represents real and verifiable carbon reductions equal to the amount represented by the credit.

Carbon offset credit use should complement, not replace, direct decarbonization. Companies can use carbon credits to contribute to global climate action through Beyond Value Chain Mitigation — measures to prevent, reduce or remove emissions outside a company's value chain — and augment their science-aligned decarbonization targets.

Crediting process

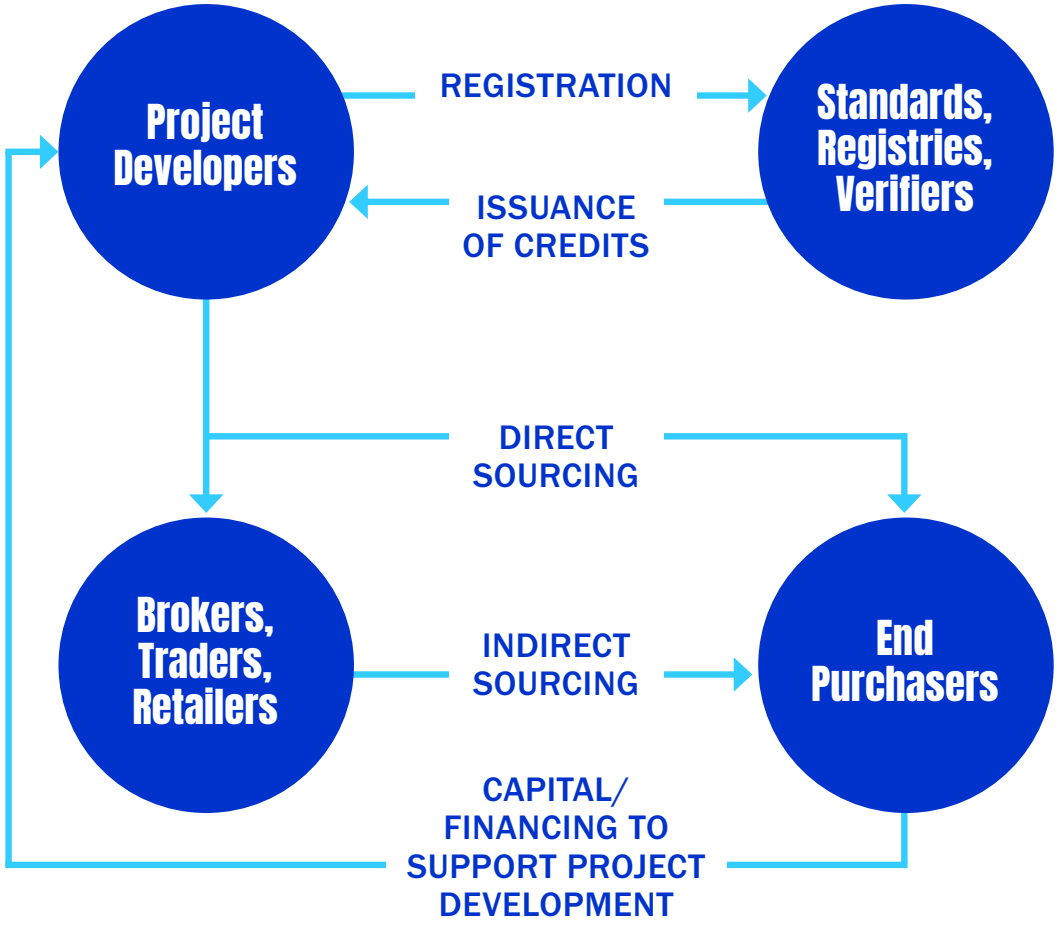
Carbon markets are one potential mechanism to mobilize capital and scale the necessary technologies and solutions to avoid methane emissions from livestock systems. An emission unit issued by a carbon crediting program represents a reduction or removal of greenhouse gases, relative to a baseline scenario. A carbon credit is uniquely serialized, issued, tracked, retired and cancelled through an electronic registry.

- Individual farms can participate in the generation of carbon credits through implementing practice switches to reduce emissions that would have otherwise occurred as part of a business-as-usual process in the absence of revenue offered by carbon credits.
- Project developers may assist farm operators with quantifying and verifying their starting level of emissions, otherwise referred to as baseline emissions, with a recognized third party, as well as those reduced emissions resulting from the intervention.
- Farmers can register and sell those reduced emissions as credits with a relevant carbon crediting registry, typically in collaboration with a project developer, that facilitates transactions with buyers. The revenue from the sale goes back to farms and any relevant project developers. Figure 1 depicts the different types of carbon marketplaces and stakeholders operating within them.

FIGURE 1: CARBON MARKET STRUCTURE

Organizations that design, develop and operate carbon projects and sell the resulting credits into the market.

Entities that set minimum requirements for the creation and issuance of credits and/or third parties that conduct due diligence or auditing.



Intermediaries that provide liquidity, distribution and other services which can increase overall participation in the market.

Typically companies or other institutions seeking to offset their own emissions and/or help support climate solutions by purchasing and retiring carbon credits.

Source: Carbon Market Principles (jpmorganchase.com)

There are both voluntary and regulatory carbon offset markets to support reducing greenhouse gas emissions in line with the United Nations Framework Convention on Climate Change (UNFCCC) and Global Methane Pledge.



Voluntary Marketplaces: There are multiple voluntary marketplaces through which livestock producers can generate carbon credits that other entities can buy. These entities are primarily corporates beyond the agriculture value chain, that are seeking to voluntarily contribute to meaningful climate action. The overall global marketplace for voluntary carbon credits (of which livestock-related credits are a part) is estimated at $2 billion for climate action in 2022 but is expected to be worth upward of $50 billion in 2030.[15]



Compliance Marketplaces: National and regional governments have established compliance marketplaces, also known as emissions trading systems (ETS), that function within cap-and-trade climate regulations. They each have different legislative emissions reductions targets, as well as pricing mechanisms. Capped entities, such as energy and heavy industry in California, Eastern U.S., Alberta, and Australian cap-and-trade programs can purchase credits generated by projects that reduce livestock methane emissions and use these offset credits towards their compliance obligation each year.[16] Regulatory markets involve an annual emissions cap set by the regulatory authorities of a specific state or nation. The emissions allotments within the cap can then be traded between regulated actors. Livestock play an important role in several regulatory markets.

The Regional Greenhouse Gas Initiative (RGGI) covers the states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont and Virginia to cap and reduce CO_2 emissions from the power sector.



Fuel Standards: National and sub-national level regulations designed to decrease the carbon intensity of transportation fuel pools by incentivizing a range of low-carbon and renewable alternatives, including livestock manure-produced biogas that contains methane, through fuel standards. Fuel standards are implemented and regulated through the government and can either complement a compliance marketplace or stand-alone. The only fuel standards covered in the report are located in the United States.

Another source of funding for livestock emissions reduction is via insetting markets, which enable companies to purchase credits from emissions reduction projects within their same value chain. Credits created within insetting markets are purchased by companies who want to address their Scope 3 emissions.[17] Insetting markets enable companies to reduce their value chain emissions without having to directly implement emissions reduction projects themselves. Like offset credits, inset credits also require MMRV in order for reductions to be quantified and accurately applied toward corporate climate reporting. While some of the methodologies in this report are being used for both offsetting and insetting projects, the analysis of this report is limited to the methodologies' use within offset markets, and MMRV systems and quality initiatives within the insetting space are outside of the scope of this report.

Scope 3 emissions are emissions that an entity (such as a corporation) indirectly affects in its value chain, also referred to as value chain emissions.

With the large number of countries implementing domestic crediting schemes as part of their climate policies, as well as growing private sector actions and corporate commitments to net zero targets, the market for carbon credits generated from projects reducing methane emissions from reduced enteric emissions and improved manure management is expected to expand.



Governance

Compliance markets and fuel standard programs are created by legislation and regulated by government bodies who oversee the creation and trading of credits. Voluntary markets are self-regulated and there are a number of organizations that play a role. The quality of a credit depends on multiple factors related to governance at the program level (i.e., requirements for all credits issued by a particular organization, regardless of credit type) as well at the methodology level.

COMPLIANCE MARKETS

The Compliance Markets (also called Regulatory Markets) exist at national, state and local levels in many places around the world with different legislative emissions reductions targets and pricing mechanisms. Compliance markets involve an annual emissions cap set by the regulatory authorities of a specific state or nation. The emissions allotments within the cap can then be traded between regulated actors. Because of this, compliance markets generally provide greater price transparency and built-in demand. This can better facilitate on-farm planning to implement methane reduction activities, for example, the construction or purchase of high capital cost manure management systems. However, this does not necessarily mean that credits generated within a compliance system are of a higher quality. Additionally, changing policy priorities can cause instability over time as governments have the power to restructure programs including what types of projects can generate offsets.

VOLUNTARY MARKETS

The voluntary markets are governed and supported by a series of organizations, non-profits and collaborative initiatives that govern carbon credit creation. Voluntary markets are underpinned by legal contracts that link the voluntary creation, marketing and purchases of carbon credits. The major voluntary credit registries regulate the supply side of the market through their published project standards (methodologies), verification processes for projects and through the marketplaces they set up which facilitate the listing, purchase and retirement of credits. Additionally, credits created for these voluntary marketplaces also go through an audit process with a third party verification and validation body before they can be registered, adding another layer of oversight to the process. Voluntary carbon market registries are also subject to scrutiny from both media and independent quality rating agencies that put public pressure on registries to continually improve and maintain the integrity of credits in the marketplace. Generally, there is a lack of price transparency for credits generated within voluntary markets; these opaque markets rely on carbon brokers as the primary method of price setting.

Some of the key players involved in the above regulation are:

Carbon crediting programs, also known as registries, that develop and approve crediting methodologies as well as enable the purchase and retirement of credits through online registries. There are four major carbon-crediting programs that act as registries for the voluntary carbon market:

- American Carbon Registry (ACR)
- Climate Action Reserve (CAR)
- Gold Standard
- Verra

Accreditation bodies and integrity initiatives are independent bodies that help govern the carbon market. These organizations help structure the market and improve market transparency by providing claims guidance on the credit demand (buyer) side and shaping standards and regulations on the credit supply side. Some of these organization include:

- Carbon Credit Quality Initiative (CCQI)
- GHG Protocol (GHGP)
- International Carbon Reduction and Offsetting Accreditation (ICORA)
- Integrity Council for the Voluntary Carbon Market (ICVCM)
- Science Based Targets Initiative (SBTi)
- Voluntary Carbon Markets Integrity Initiative (VCMI)



Credit Quality

There are various levels of quality and rigor among carbon programs and protocols. Neither compliance nor voluntary credits are inherently superior in quality; however, voluntary markets are often seen as a testing ground for crediting methodologies before they might be adopted by compliance schemes.

Issuing and trading poor quality credits threatens the functioning of carbon markets as a whole as well as overall progress toward global climate goals. Additionally, issuing or purchasing poor quality credits poses a reputational risk to the organizations involved. Up until this point there have been disparate efforts to evaluate credit integrity, but the onus of due diligence has still largely fallen on credit buyers, creating confusion and sometimes mistrust.

ICVCM is the leading independent governance body for the voluntary carbon market system. In 2023 the ICVCM launched the Core Carbon Principles, a set of definitive global threshold standards for carbon credit quality. This year the ICVCM assessed programs covering 98% of the voluntary carbon market are issuing CCP-approval labels for methodologies that meet their integrity threshold in batches throughout 2024 and 2025. This label is a demarcation intended to build trust in the voluntary carbon market and unlock investment by making it easier for buyers to recognize and put a price on high-integrity carbon credits. The CCP label denotes that project methodologies meet the threshold for each of the 10 quality criteria.

While the CCP label is a major step forward for the voluntary carbon market, the ability to most accurately quantify, monitor, report and verify emissions reductions is constantly evolving based on scientific and technological advances. The CCP label represents the threshold for a quality credit; however, there are still improvements that can and should be made to methodologies in the livestock space to continually improve the accuracy, impact and integrity of credits issued for these credit types.

Voluntary and compliance carbon markets are a potential source of much-needed finance to help the agriculture sector realize its potential for climate mitigation. The scientific community and carbon registries need to actively collaborate to regularly update existing methodologies with the best available science. The variety of distinct crediting methodologies for livestock emissions reductions may lead to confusion and reticence on behalf of both project developers and buyers of carbon credits. This report aims to illuminate the characteristics of current crediting protocols by providing a high-level assessment of the current methodologies and mechanisms and their key differences. Additionally, the report highlights where there are currently opportunities across the existing methodologies for livestock emissions reductions to improve the robust quantification of emissions and social benefits and safeguards.

Crediting Methodologies for Reducing Livestock Methane Emissions



This report provides a global overview of 25 unique carbon crediting methodologies governed by 11 programs that quantify and certify reduced GHG emissions from livestock systems, primarily methane. These methodologies outline the specific procedures and methods for implementing, measuring, monitoring, reporting and verifying project activities that need to be followed to ensure that emissions reductions can be accurately and transparently estimated. At the time of this report, livestock producers globally can generate and sell verified methane emissions reductions (converted to CO_2e GWP100) to various buyers through programs including Verra, Gold Standard, CAR and the United Nations Clean Development Mechanism (CDM).[18]

While the UN CDM registry is no longer accepting new projects, UN CDM methodologies can be used to register projects in the voluntary carbon market, such as under the Verra VCS and Gold Standard registries, which is the basis for the inclusion of these methodologies in our review.

In the United States, livestock producers can also generate credits through the Regional Greenhouse Gas Initiative (RGGI), the California Air Resources Board (CARB) Cap-and-Trade, CARB Low Carbon Fuel Standard (LCFS) and the U.S. Environmental Protection Agency Renewable Fuel Standard (RFS). The governments of Australia, Alberta and Canada provide crediting pathways for livestock through Emissions Trading Systems (ETS).

Furthermore, this report assesses to what extent each of the methodologies addresses the quality objectives detailed in Table 3 determining a high-quality carbon credit generated from implementation of such projects. This report aims to organize and compare the various options that exist and how each of these options compares against a set of key quality objectives. This report identifies overarching research gaps across all project types and identifies recommendations for carbon market registries and the scientific community that would strengthen the integrity of credits generated from livestock methane reduction projects.

The goal of this report is to help readers better understand the challenges and opportunities of utilizing carbon markets to scale the practices needed to reduce livestock methane with integrity.

Existing methodologies are aimed at two types of reductions: reducing enteric methane emissions from animal digestive processes (enteric emissions) and reducing methane emissions from livestock manure management. Reductions from carbon projects are used to generate credits, with each credit representing one ton of CO_2e, calculated with a 100-year global warming potential (GWP100). These credits can then be traded within compliance or voluntary carbon marketplaces.



REDUCED ENTERIC METHANE EMISSIONS METHODOLOGIES

Table 1 outlines the enteric methane emissions reduction solutions for which the reviewed methodologies generate credits and the applicable geographic scope. EDF's report on enteric emissions reduction opportunities details the suite of solutions in more detail.[19] Solutions can reduce absolute emissions, emissions intensity and sometimes both (see Box 2). The definitions for terminology such as "feed additives," "feed ingredients," "feed supplements" and "food additives" are used differently by different methodologies. There are not currently industry-wide standards for defining these terms. There are official government definitions with overlap in meaning between some of the terms and the regulatory status of such products is rapidly evolving. Therefore, for this report, we use "feed additives" as an umbrella term to refer to a broad category of strategies encompassing the use of products fed to livestock — in these cases with the goal of reducing enteric methane emissions. However, when discussing specific methodologies, we use their chosen terminology.

TABLE 1: CARBON CREDITING METHODOLOGIES FOR ENTERIC METHANE REDUCTION SOLUTIONS

Crediting Protocol	Applicable Animal Species	Geographic Scope	MITIGATION ACTIVITY			
			Feed Additives and diet improvement	Genetic Improvements	Herd Management	Animal Health
Alberta Emissions Offset System: Quantification protocol for selection for low residual feed intake in beef cattle	Beef cattle	Alberta		X		
Alberta Emissions Offset System: Quantification protocol for reducing greenhouse gas emissions from fed cattle	Beef cattle	Alberta	X	X	X	
Australian Emissions Reduction Fund: Reducing emissions by feeding dietary additives to milking cows	Dairy cattle	Australia	X			
Australian Emissions Reduction Fund: Reducing emissions by feeding nitrates to beef cattle	Beef cattle	Australia	X			
Australian Emissions Reduction Fund: Beef cattle herd management	Beef cattle	Australia			X	
Canada's GHG offset credit system Reducing enteric methane emissions from beef cattle (Draft)	Beef cattle	Canada	X	X	X	X

Crediting Protocol	Applicable Animal Species	Geographic Scope	MITIGATION ACTIVITY			
			Feed Additives and diet improvement	Genetic Improvements	Herd Management	Animal Health
Gold Standard: Reducing methane emissions from enteric fermentation in dairy cows through application of feed supplements	Dairy cattle	Global	X			
Gold Standard: Methodology for quantification of GHG emissions reductions from improved management in smallholder dairy production systems using a standardized baseline	Dairy cattle	Global	X	X		X
Gold Standard: Methane emissions reduction from enteric fermentation in beef cattle through application of feed supplements	Beef cattle	Global	X			
U.N. CDM: AMS-III. BK. Strategic feed supplementation in smallholder dairy sector to increase productivity	Dairy cattle	Global	X			
Verified Carbon Standard (VCS) VM0041: Methodology for the reduction of enteric methane emissions from ruminants through the use of feed ingredients	All ruminants	Global	X			

Within the scope of this report, feed additives are a product fed to livestock through their diets with the goal of reducing enteric methane emissions.

Seven of the methodologies evaluated in this report generate credits for emissions reductions resulting from administering feed additives to livestock, some of which may have adverse impacts on **human food safety, animal health and the environment** (e.g., bromoform, the active ingredient in some solutions being developed, is an ozone-depleting substance and animal studies show chronic, elevated exposure can result in negative health impacts).[20]

Feed additives administered to livestock for emissions reductions must have a rigorous safety review. Most methodologies assessed do not consider potential animal health nor human food safety impacts as independent criteria. Some methodologies establish regulatory approval as a criterion for qualification, but this language is vague as regulatory treatment can vary between national and sub-national level jurisdictions.

In general, products that may affect animal health and human food safety are regulated by national or sub-national authorities, such as the U.S. Food and Drug Administration, California Department of Food and Agriculture, Health Canada and the Canadian Food Inspection Agency, and the European Food Safety Authority. The regulatory process for products with environmental claims is currently undergoing review in the U.S. at the time of this report.

As methodologies further develop, they should align on how to best manage requirements pertaining to regulatory review and consider common rigor in assessing safety.

Below are the varying guidelines for applicable methodologies reviewed in this report for meeting local regulation and safety requirements.

VCS — Methodology for the reduction of enteric methane emissions from ruminants through the use of feed ingredients:

"The feed ingredient must have been demonstrated to comply with all feed and food regulations in each national or subnational (including local) jurisdiction in which it is consumed. Where conflict arises among regulations, the most stringent standard must apply. The feed ingredient must have no negative health impacts on the animal to which it is fed. This must be shown through regulatory approval and the submission of published evidence demonstrating no negative impacts on animal health when administered in accordance with its intended conditions of use."[21]

The protocol does not specify requirements for "published evidence" such as study requirements, peer-reviewed requirements or number of studies needed.

Gold Standard — Methodology for Quantification of GHG Emissions Reductions from Improved Management in Smallholder Dairy Production Systems using a Standardized Baseline:

"The project proponent shall aim to meet or exceed national guidelines where these exist, and where national guidelines do not exist the project proponent shall develop project-specific guidelines based on international guidelines on animal welfare in dairy production."[22]

Gold Standard — Methane Emissions Reduction from Enteric Fermentation in Beef Cattle Through Application of Feed Supplements:

"All feed additives applied under the project activity must be officially registered for use with beef cattle in the project country and provide evidence for such authorization by the respective country authority."

U.N. CDM — AMS-III.BK. Strategic feed supplementation in smallholder dairy sector to increase productivity:

"The feed supplement shall be formulated in accordance with the nutritional requirements of the intended ruminants in the host country and shall be in compliance with the local regulation; potential health limitations or safety restrictions to animals for using the project feed additive shall be identified and a mechanism for informing participating farmers (e.g. training) shall be developed and implemented"[23]

Canada's GHG offset credit system: Reducing Enteric Methane Emissions from Beef Cattle

(Draft): "All feed, feed additives, or drugs delivered to cattle must be approved for regulatory use in Canada and used in accordance with all relevant legislation."[24]

Key Takeaways:

- Most methodologies assessed do not evaluate potential animal health and human food safety impacts as independent criteria.
- Some methodologies establish regulatory approval as a criterion for qualification; however, regulatory treatment of feed additives varies between jurisdictions.
- Under a business-as-usual scenario, products may be marketed without regulatory review and approval in some countries and/or regions.

AVOIDED MANURE METHANE EMISSIONS METHODOLOGIES

When manure is stored in conditions lacking oxygen (i.e., anaerobic), methane is created by microbial decomposition of the manure which, without controls is emitted to the atmosphere. Generally, decreasing the amount of time that manure spends in anaerobic conditions reduces the amount of methane created and potentially emitted. Methane from anaerobic manure digestion can also be captured and destroyed using various technologies.

The manure handling strategies and technologies listed below are each included in globally applicable carbon-crediting methodologies, which can be used to generate carbon credits by reducing or avoiding methane emissions:

- Biogas capture and upgrading for energy generation (at either household or industrial scale);
- Biogas capture and upgrading for fuel production;
- Biogas capture and destruction through flaring; or
- Preventing the creation of biogas through solid-liquid separation or other aerobic manure management techniques.

The appropriateness of each of these solutions varies based on the existing production system and manure management strategies already in place.

The scale of the livestock system where the solution is being used also matters. Intensive management at scale will look different than smallholder production. Because of this, some carbon market protocols are specifically developed for implementation in smallholder production systems or at the household scale (see Table 10).

For operations that keep animals in confinement for all or part of the year, such as most hog finishing facilities and many dairies in the U.S., business-as-usual manure management practices typically involve open-air anaerobic lagoon treatment or storage and then direct field application of manure. This results in methane emissions from anaerobic manure lagoons and storages.

Table 2 outlines the manure management solutions for which the reviewed methodologies generate credits and the applicable geographic scope.

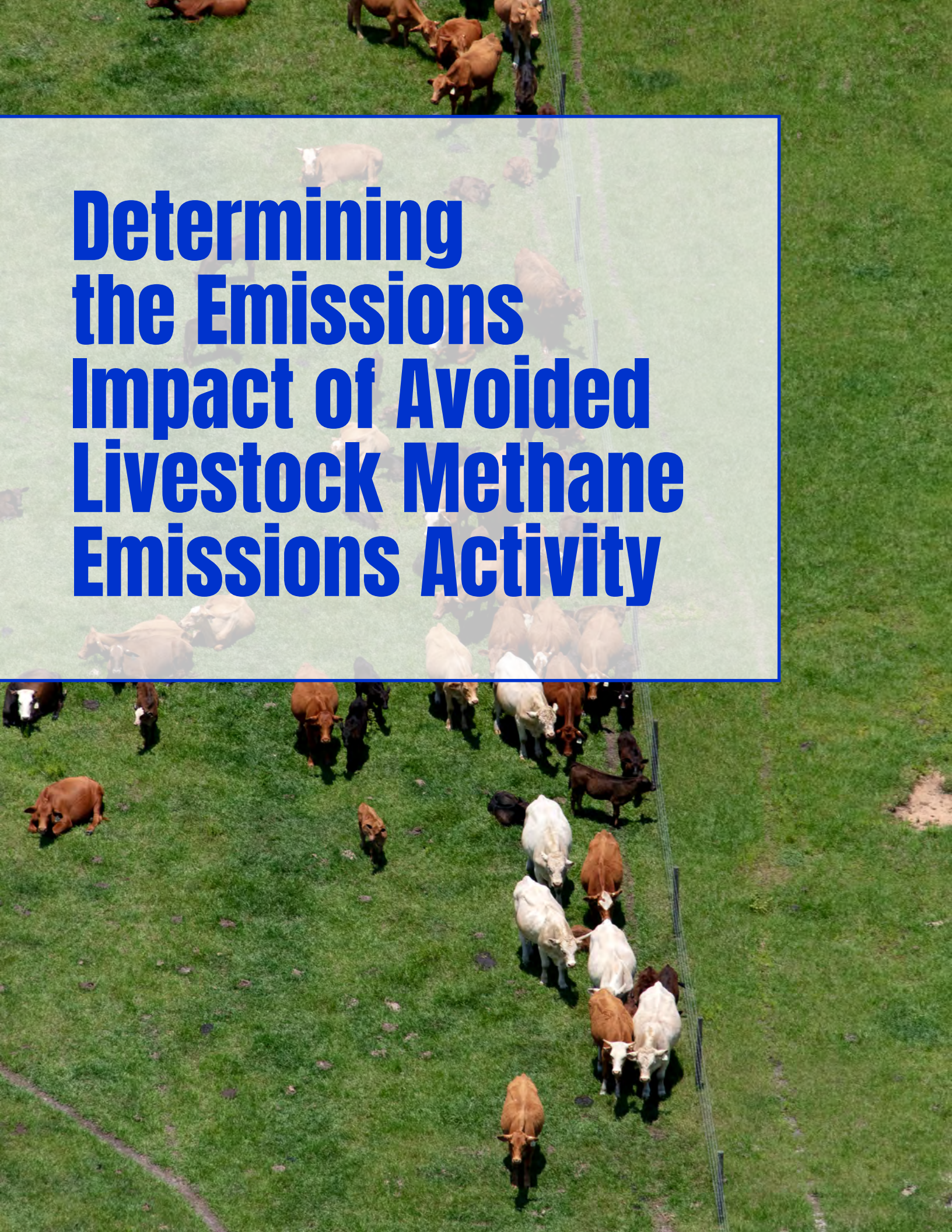


TABLE 2: CARBON CREDITING METHODOLOGIES FOR PRACTICES AND TECHNOLOGIES THAT REDUCE MANURE METHANE EMISSIONS

Crediting Protocol	Applicable Animal Species	Regional Applicability	MITIGATION ACTIVITIES			
			Biogas capture & upgrade for energy generation	Biogas capture & upgrade for fuel production	Covering & flaring of captured biogas	Methane avoidance through solid/liquid separation
Gold Standard: GHG emissions reductions from manure management systems and municipal solid waste (based on approved CDM methodologies: ACM 10, 22, and 73)	All ruminants, swine, and poultry	Global	X	X		
Gold Standard: Methodology for animal manure management and biogas use for thermal energy generation	Any livestock	Global	X	X		
Climate Action Reserve: U.S. livestock project protocol V4.0, Manure methane digesters	Dairy cows and swine	U.S.	X	X	X	
California Air Resources Board: Low carbon fuel standard regulation	Dairy cows and swine	U.S.	X	X		
California Air Resources Board: Compliance offset protocol, Capturing and destroying methane from manure management systems	Dairy cows and swine	U.S.		X	X	
U.S. EPA: Renewable fuel standard program	Any livestock	U.S.		X		
U.S. Regional Greenhouse Gas Initiative: Model offset consistency applications and model monitoring and verification reports	Any livestock	U.S.	X	X	X	

Crediting Protocol	Applicable Animal Species	Regional Applicability	MITIGATION ACTIVITIES			
			Biogas capture & upgrade for energy generation	Biogas capture & upgrade for fuel production	Covering & flaring of captured biogas	Methane avoidance through solid/liquid separation
Alberta: Quantification protocol for biogas production and combustion	Dairy cows and swine	Alberta	X	X		
Australia: Animal effluent management	Dairy cows and swine	Australia	X	X	X	
U.N. Clean Development Mechanism, ACM0010: GHG emissions reductions from manure management systems	All ruminants, swine, and poultry	Global	X		X	
U.N. Clean Development Mechanism, AM0073: GHG emissions reductions through multi-site manure collection and treatment in a central plant	All ruminants, swine, and poultry	Global	X		X	
U.N. Clean Development Mechanism, AMS-III.D.: Methane recovery in animal manure management systems	Any livestock	Global	X			
U.N. Clean Development Mechanism, AMS-III.R.: Methane recovery in agricultural activities at household/small farm level	Any livestock	Global	X		X	
U.N. Clean Development Mechanism, AMS-III.Y: Methane avoidance through separation of solids from manure treatment systems	Any livestock	Global				X

Note that Gold Standard and Verra's VCS Program recognize U.N. CDM methodologies for use within their registries.



Determining the Emissions Impact of Avoided Livestock Methane Emissions Activity

The methodologies used by crediting programs to estimate the emissions impact of mitigation activities should consider several CCPs to be considered high-integrity credits.[25] This report assesses how each methodology addresses four of the 10 CCPs for identifying high-quality carbon credits. These four principles below and the corresponding criteria were selected to narrow the focus of this report based on EDF's expertise as to what criteria are most relevant to this project type.

TABLE 3: CORE CARBON PRINCIPLES CONSIDERED IN THIS REPORT

Core Carbon Principle	Description
Methodology-level: *Emissions Impact* — Additionality	Emissions reductions or removals from the mitigation activity shall be additional, i.e., they would not have occurred in the absence of the incentive created by carbon credit revenues.
Methodology-level: *Emissions Impact* — *Permanence*	The GHG emissions reductions or removals from the mitigation activity shall be permanent or, where there is a risk of reversal, there shall be measures in place to address those risks and compensate reversals.
Methodology-level: *Emissions Impact* — Robust quantification of emissions reductions and removals	The GHG emissions reductions or removals from the mitigation activity shall be robustly quantified, based on conservative approaches, completeness and best available scientific methods that consider uncertainty associated with models and emissions factors used. Key criteria include: • Accounting for all significant sources and sinks of methane and other pollutants (e.g., N_2O and ammonia) • Setting an appropriate baseline • Comparable quantitative methods for baseline and mitigation activity emissions • Considering and minimizing leakage • Crediting periods appropriate to the type of mitigation activity • Conservative use of default values and appropriate discounting to address uncertainty.
Program-level: Sustainable development benefits and safeguards	The carbon-crediting program shall have clear guidance, tools and compliance procedures to ensure mitigation activities conform with or go beyond widely established industry best practices on social and environmental safeguards while delivering positive sustainable development impacts.

Each program has emissions monitoring requirements that outline how producers must go about quantifying their baseline and project emissions. The quantification and reporting requirements for each of the methodologies reviewed in this report vary greatly. Some methodologies allow the direct measurement of methane emissions, however, most methodologies call for the quantification of emissions through validated models that pull in standardized values for the emissions reduced by a specific practice.

The following sections describe the approaches taken to quantify baseline and project emissions and identify all potential sources of emissions from project activity, including those from leakage.



ADDITIONALITY

Additionality is a minimum entry requirement for any credible carbon-crediting program methodology. This Core Carbon Principle assesses the likelihood that a mitigation activity typically would not have taken place in the absence of the added incentive created by the carbon credits.[26] This is crucial for ensuring that generated and purchased carbon credits truly represent emissions reductions that would not have happened otherwise.

Table 4 summarizes multiple approaches for additionality that, depending on the type of mitigation activity, can provide strong assurances.[27]

TABLE 4 — APPROACHES FOR ADDITIONALITY

	Description
Legal	Assurance that the mitigation activity is registered only if the resulting carbon credits represent emissions reductions or removals that exceed those required due to relevant legal requirements that are enforced.
Financial	Demonstration that the mitigation activity would not be the most economically attractive scenario in the absence of carbon credits. Assessment of economic parameters such as relevant costs (capital expenditures, operational expenditures) and revenues, including subsidies or official development aid, where applicable, over a 10-year period to demonstrate that the finance derived from the carbon revenue is material to the financial viability of the project.
Prior consideration of carbon credits	Publicly documenting evidence that project participants considered the potential to earn revenue through carbon credits prior to the start date of the mitigation activity, with a reasonably limited time period between the documented date of the evidence and the later date of registration of the mitigation activity.
Market penetration/ Common practice	Evidence that the technology or mitigation activity is not yet common practice within a spatial area, also referred to as business-as-usual, by demonstrating a low market penetration rate. This is expressed as a percentage of all implemented technologies or mitigation activities that provide the same service, typically within a specified spatial boundary.
Barriers	Evidence that the carbon credit revenues are the decisive element in overcoming an identified barrier, such as: • financial — loans or other forms of financing are not accessible for the type of mitigation activity and country due to financier's assessment of risks • institutional — the investor not being the beneficiary of cost savings associated with the investment or availability • informational — e.g., household's lack of awareness of the availability or cost savings of a technology • other barriers specific to the mitigation activity and/or region where the mitigation activity is implemented if these barriers are explicitly identified and elaborated in the relevant quantification methodology or other program documents

We assessed the additionality requirements for all carbon-crediting programs that have methodologies for avoided livestock methane and found that:

- All analyzed programs require proof of some type of additionality to a greater or lesser extent, with the exception of California's Low Carbon Fuel program and the U.S. EPA Renewable Fuel program.
- Legally required practices are not accepted under any of the programs, although some methodologies allow legally mandated practices if the project owner can demonstrate that the relevant laws or regulations are systematically not enforced.
- Most crediting programs require investment analysis to demonstrate financial additionality and/or barrier analysis as either an alternative or in addition to the investment analysis.[28]

For example, see SustainCert "Must my Gold Standard project demonstrate ongoing financial need?"

- Under the U.N. CDM, it is also possible to use Methodological Tool 32 Positive List of Technologies, which includes biogas digesters for cooking and off-grid electricity generation from biogas (small units up to 100 kW, total up to 15 MW).[29] This methodological tool contains lists of technologies and associated conditions that confer automatic additionality to CDM project activities and CDM Programs of Activity that apply such technologies and meet specified conditions.
- Most methodologies specify that additionality needs to be demonstrated at the project level, whereas some require a broader, sector-wide assessment specific to project type or technology. The Alberta Carbon Offset Program is unique in that additionality is demonstrated at the methodology level which is like the project type approach. Also unique to this program is the fact that additionality can be demonstrated based solely on penetration rate, where this is determined to be relevant and measurable.
- Retroactive crediting is restricted in all programs. In some programs, projects cannot receive any credits for the period before the date of their registration or submission of application, while others impose restrictions regarding the length of crediting period before project registration.

Table 11 in the appendix provides a detailed overview of the approaches used throughout each reduced livestock manure methane methodology with respect to additionality.

PERMANENCE

Permanence refers to the longevity of GHG emissions reductions or removals from the mitigation activities. It is important that the reductions or removals are permanent or, where there is a risk of reversal, have measures in place to address those risks and compensate for reversals. Across project types in all sectors, there are various degrees of permanence and reversal risks. For example, nature-based projects that capture carbon in biomass or soil, run the risk of stored carbon getting released back into the atmosphere through changes in management practices or natural disasters.

Avoided methane emissions from both reduced enteric emissions or improved manure management are permanent and irreversible by nature, a benefit of this project type.



ROBUST QUANTIFICATION OF EMISSIONS REDUCTIONS AND REMOVALS

Within the CCPs robust quantification requirement is that "the GHG emissions reductions or removals from the mitigation activity shall be robustly quantified, based on conservative approaches, completeness and scientific methods." Robust quantification of emissions reductions is essential to ensuring that emissions traded in markets represent actual emissions reductions and is necessary for proper accounting of carbon emissions at the company, sub-national, national and global level. Accurate accounting of carbon offsets is necessary to making progress towards climate goals and protecting the integrity of carbon markets as a whole. Robustly quantifying emissions reductions consists of the following elements:

- Setting an appropriate baseline
- Appropriate selection and monitoring of emissions sources and sinks, to determine both baseline and project emissions
- Identification and appropriate estimation of leakage of emissions including other GHGs (e.g., N2O)
- Conservative estimates and uncertainty values

According to the CCPs, the baseline scenario is defined as "a description of the situation and the outcome that is predicted or assumed to occur in the absence of the incentives created by the carbon credits and their associated mitigation activities, while holding all other factors constant."[30] In other words, it is an emissions level against which emissions reductions of a project are compared, in order to determine the emissions impact of a crediting project. Baselines are used for carbon market projects, as well as at the company and country level.

Baseline emissions levels directly determine the number of credits that will be generated by any given carbon project, and therefore accurately calculating baseline emissions levels is a key integrity issue for carbon markets.

However, it is important to note that measurement and modeling technologies are continuously evolving, and baselines set in the past might not reflect future modeling best practices. This highlights a need for carbon registries to ensure that baselines set prior are periodically revisited and updated to reflect the best available data.

Individual methodologies may allow project developers to choose from different approaches to determine baseline and project emissions, and overall emissions reductions, to account for the fact that not all relevant measurements and parameters may be available to project developers. These approaches can be divided into three main types:



Baseline:

- **Gross Energy Intake Model:** Baseline and project emissions are determined using a model which estimates enteric methane production based on the quantity and quality of feed used and weight of the animal. The calculation factors can either be internationally or nationally accepted default values (e.g., from IPCC), or, in some cases, sourced from relevant published research. This model is based upon animal diet nutritional changes but does not work to estimate emissions reductions as a result of the addition of enteric methane inhibiting products or changes in animal health.[31]

- **Direct measurement:** Enteric methane production is assessed through direct measurement from a sample of animals. This method should work for changes in diet or animal health or addition of enteric methane inhibiting products. It should be noted that with feed additives, the method of measurement must take into account diurnal or physiologic factors.[32]

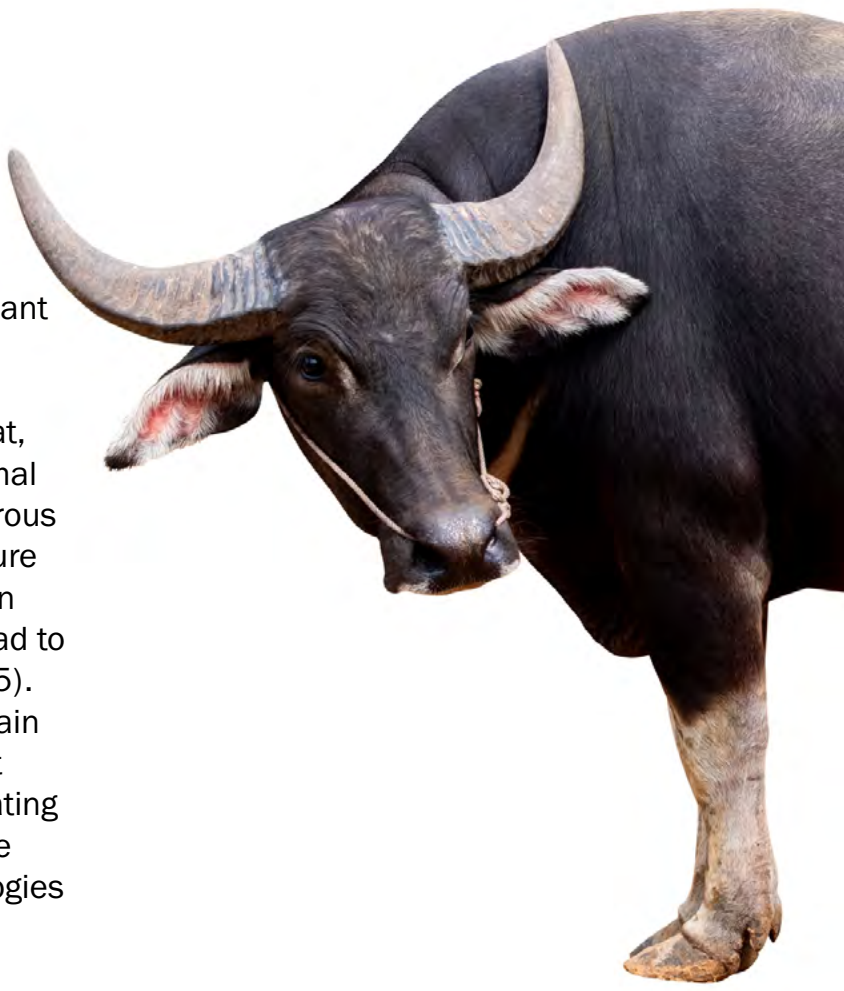
- **Emissions reduction factor (ERF):** An enteric methane emissions reduction factor is used to determine the reduction of enteric methane in the project scenario resulting from the intervention. This is most often used with the addition of enteric methane inhibiting products. The ERF can be sourced from published research or from international guidance documents like the IPCC or FAO reports.

Nineteen of the 25 methodologies reviewed set the project boundary to contain both direct emissions from the intervention itself as well as indirect emissions from upstream or downstream impacts of the intervention such as the production of feed additives and manure management and use. Methodologies may also require estimates of direct and indirect emissions of N_2O and potentially CO_2 from sources such as manure management and use, transportation, production of feed additives, etc. to be made in addition to methane. It is important that methodologies account for all the possible new sources of emissions introduced by an intervention to be able to capture the net emissions impact.

For example, the production and transportation of feed additives must be accounted for in order to understand the true net benefits of this intervention on net emissions. For manure management, projects may lead to change in emissions of other gases such as N_2O, therefore, including N_2O in net GHG calculations is important to understanding the full climate benefit of manure methane reduction projects. See Tables 5 and 6 for information on the project boundary of each methodology analyzed.

Enteric methane emissions baselines

Enteric methane emissions are a significant source of methane, globally.



The amount of absolute enteric emissions from each individual ruminant varies based on a variety of factors. Moreover, the intensity of emissions per unit of product, such as milk, meat, leather or wool, from the specific animal can vary significantly based on numerous factors. Setting the baseline to measure absolute reductions is important when considering multiple variables that lead to enteric methane emissions (see Box 5). Table 5 provides a summary of the main differences in approaches throughout methodologies with respect to calculating baseline and project emissions for the enteric methane reduction methodologies reviewed in this report.

TABLE 5: APPROACHES TO DETERMINING BASELINE AND PROJECT EMISSIONS THROUGHOUT THE ENTERIC METHANE REDUCTION METHODOLOGIES

Protocol	Approach to estimating reductions	Estimation of upstream and/or downstream emissions required	Estimation of net GHGs
Gold Standard: Reducing methane emissions from enteric fermentation in dairy cows through application of feed supplements	Gross Energy Intake Model or Direct measurement	Upstream (feed additive manufacture) and downstream (manure management and use)	CH_4, CO_2 (feed additive manufacture) and N_2O (manure management and use)
Gold Standard: Methodology for quantification of GHG emissions reductions from improved management in smallholder dairy production systems using a standardized baseline	Gross Energy Intake Model	Upstream (feed additive manufacture) and downstream (manure management and use)	CH_4, CO_2 (feed additive manufacture) and N_2O (manure management and use)
Gold Standard: Methane Emissions Reduction from Enteric Fermentation in Beef Cattle Through Application of Feed Supplements	Emissions Reduction Factor (ERF) or Direct Measurement	Upstream (feed additive manufacture) and downstream (manure management)	CH_4, CO_2 (feed additive manufacture and transport) and N_2O (manure management and use; pasture management)
Verified Carbon Standard: Methodology for the reduction of enteric methane emissions from ruminants through the use of feed ingredients	Emissions Reduction Factor (ERF) or Direct Measurement	Upstream (feed additive manufacture and transport) and downstream (manure management and use)	CH_4, CO_2 (feed additive manufacture & transport) and N_2O (manure management and use)
Canada's GHG offset credit system: Reducing enteric methane emissions from beef cattle (Draft)	Gross Energy Intake Model	Upstream and downstream emissions not considered	CH_4, CO_2, and N_2O (manure storage and handling at project site)

Protocol	Approach to estimating reductions	Estimation of upstream and/or downstream emissions required	Estimation of net GHGs
Alberta Carbon Offset Program: Quantification protocol for selection for low residual feed intake in beef cattle	Gross Energy Intake Model	Downstream (manure management and use)	CH_4, N_2O (manure management and use)
Alberta Carbon Offset Program: Quantification protocol for reducing greenhouse gas emissions from fed cattle	Gross Energy Intake Model	Downstream (manure management and use)	CH_4, N_2O (manure management and use)
U.N. Clean Development Mechanism, AMS-III. BK.: Strategic feed supplementation in smallholder dairy sector to increase productivity	Gross Energy Intake Model	No	CH_4
Australian Emissions Reduction Fund: Reducing emissions by feeding dietary additives to milking cows	Gross Energy Intake Model	No	CH_4
Australian Emissions Reduction Fund: Reducing emissions by feeding nitrates to beef cattle	Emissions Reduction Factor (ERF)	Downstream (manure management and use)	CH_4, N_2O (manure management and use)
Australian Emissions Reduction Fund: Beef cattle herd management	Gross Energy Intake Model	Downstream (manure management and use)	CH_4, N_2O (manure management and use)

BOX 2: MEASURING ABSOLUTE METHANE EMISSIONS REDUCTIONS VS. EMISSIONS INTENSITY REDUCTIONS

Climate mitigation efforts need to focus on the absolute amount of methane emitted. Some of the practices and technologies being implemented or considered to generate credits for reduced enteric methane emissions target absolute emissions reductions, others focus on reducing the emissions intensity of the product produced, and some may consider both. There are benefits to decreasing methane emissions intensity, especially in the long term, because it increases output and revenue to farmers with the same number of animals. However, from a climate and crediting standpoint, absolute emissions reduction is the key parameter.

It is important to note that reducing a livestock product's methane emissions intensity may or may not be associated with reducing absolute methane emissions.

A product's methane intensity can be reduced by increasing the production of the product per cow, but many of the interventions that increase productivity also increase methane emissions. If the percent increase in productivity is greater than the percent increase in methane, then the methane intensity per unit of product is decreased. It follows then that if the productivity increase per cow adds to the overall supply of product by a greater percentage than the reduction in methane intensity, then the absolute methane emissions will increase. For example, if an operation reduces the methane intensity of a unit of milk or meat produced by 50%, but the productivity is increased by more than 50%, the absolute methane emissions will increase. In this case, the climate benefits of reduced methane intensity are likely only realized over the longer term if a smaller, or at least a constant, herd size relative to the business-as-usual scenario can supply a growing demand for animal-source foods that otherwise would have required a larger increase in herd size of lower productivity animals.

Quantitative example for illustrative purposes:

Using a baseline example of 10 l milk/cow: x 10 g CH_4/l milk = 100 g CH_4/cow

- With reduced methane intensity by half, combined with a double increase in productivity, no increase (or decrease) in absolute methane: 20 l milk/cow x 5 g CH_4/l milk = 100 g CH_4/cow
- But if productivity goes up by 3x, compared to methane intensity down by 1/2, absolute methane increases: 30 l milk/cow X 5 g CH_4/l milk = 150 g CH_4/cow

As far as accounting for sellable carbon credits, absolute emissions reductions are the metric of concern. The models used by all quantification methodologies included in this review output a number which represents the total absolute emissions reductions of a project. This requires reduced carbon intensity to be multiplied by product yield to calculate absolute emissions reductions.

Absolute Emissions Definition:
Total mass of emissions, generally reported in units of carbon dioxide equivalent with a 100-year global warming potential.

- Solution examples that target absolute emissions reductions by lowering the total enteric methane emitted by the animal:
  - Genetic improvements, which could involve breeding for lower methane emissions.
  - Administering feed additives that reduce enteric methane emissions while milk or meat output is either unchanged or could increase if any of these products result in productivity gains.
- VCS carbon crediting methodology for reduced enteric methane emissions accounts for absolute project emissions reductions by way of modeled baseline emissions estimates and the use of emissions reduction factors.

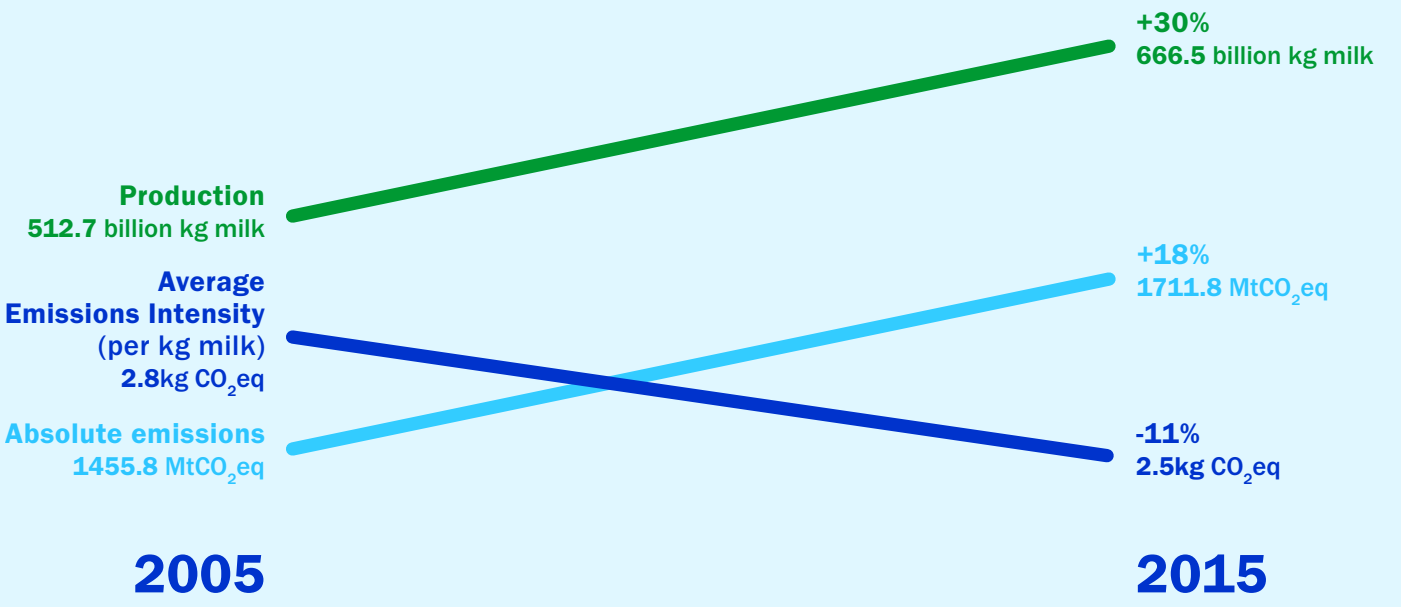
Emissions Intensity Definition:
Mass of emissions per unit of animal product, e.g., kg CO_2/kg of milk or meat.[33]

- Solution examples that aim to reduce the emissions intensity per animal by increasing the productivity of an animal (emissions per unit of milk or meat) without a similar or larger proportional increase in methane emissions:
  - Improved diet quality
  - Herd management
  - Animal health interventions
- Gold Standard and CDM enteric methane reduction methodologies account for reduced absolute enteric methane emissions by way of emissions intensity-based equations:
  - These equations account for an estimate of the amount of enteric methane emitted and the amount of milk or meat produced per animal, expressed with a ratio such as tCO_2e/kg fat corrected milk or tCO_2e/kg hot carcass weight gain
  - Multiplying the emissions intensity for the baseline and project by the productivity measure (e.g., kg fat corrected milk or kg hot carcass weight) gives baseline and project absolute emissions. Subtracting the project absolute emissions from the baseline absolute emissions gives an estimate of absolute emissions reductions.

Example:

A 2019 study conducted by the Food and Agriculture Organization of the United Nations and the Global Dairy Platform shows how emissions intensity reduction has limited but not stopped overall methane emissions from rising in the global dairy sector.[34] While dairy methane emissions intensity decreased globally by 11% between 2005-2015, overall dairy methane emissions increased by 18% globally in the same period because the overall quantity of milk produced and processed increased by 30%.[35] If emissions intensity had remained unchanged, the total emissions would have been much higher (i.e., 30% versus 18%).

FIGURE 2: THE INCREASE IN MILK PRODUCTION (BILLION KG) COMPARED TO AVERAGE EMISSIONS INTENSITY (KG CO_2EQ) AND ABSOLUTE EMISSIONS ($MTCO_2EQ$) BETWEEN 2005 AND 2015.



Source: Global Agenda for Sustainable Livestock. "Climate change and the global dairy cattle sector – The role of the dairy sector in a low-carbon future." Food and Agriculture Organization of the U.N. and Global Dairy Platform, 2018, Rome. http://www.fao.org/3/CA2929EN/ca2929en.pdf

Key Takeaways:

- Reductions to methane emissions intensity do not necessarily lead to an overall reduction of methane emissions entering the atmosphere.
- The climate benefits of reduced methane intensity where absolute methane emissions simultaneously increase, are likely only realized over the longer term if the increased productivity reduces the number of livestock needed to meet the increased demand for milk or meat.
- At the project level, all methodologies quantify and credit for reduced absolute methane emissions.

Manure methane baselines

Emissions from manure decomposition are variable and dynamic, and there are multiple parameters needed to accurately estimate these emissions such as temperature, animal diet and manure storage conditions.

For the **robust quantification of emissions reductions** there are two main approaches to establishing baseline emissions for manure projects: standardized (a standardized baseline based on type of production system within a specific country or region) and project-based (a model estimates the baseline using on-farm parameters and data). The number of parameters included in the calculation of the baseline and project emissions differs between the methodologies, although several parameters are fundamental to assessing manure management activities and are therefore common across most of the methodologies. Most of the assessed methodologies require the estimation of both direct emissions and indirect emissions of gases other than methane from project activities, such as carbon dioxide and N_2O, including the upstream and downstream emissions of these gases.



The number of parameters included in the calculation of the baseline and project emissions also differs between the methodologies. An overview of the different requirements for determining baseline and project emissions are provided below and in Table 6 on page 49.

- Methodologies reviewed use various approaches to determine baseline and project emissions including data from field surveys, simplified IPCC Tier 1 or 2 methods, direct on-site measurements and/or use of default values for specific parameters provided by IPCC or peer-reviewed research data/models. (see Table 6)
- As mentioned above, most of the assessed mechanisms use methodologies that incorporate standardized baselines established in accordance with regulations and common practice. Some of the methodologies require that the baseline emissions are modeled based on default emissions factors and equations provided in the protocol documents.
- Most of the assessed methodologies require estimation of both direct emissions and emissions reductions from the project activities and the indirect emissions caused by the project activities, including upstream and downstream emissions.
- In addition to methane emissions, most of the assessed methodologies also require that project proponents include emissions of CO_2 (for example, from stationary and mobile combustion) and N2O (for example, from manure treatment and land application) into their estimates of the project impacts. However, seven of the reviewed methodologies (see Table 6) do not require project proponents to include the calculation of N_2O in baseline or project emissions. The digestate from anaerobic digesters when stored in an open lagoon, commonly known as a secondary lagoon, could result in emissions of N_2O given the low carbon to nitrogen ratio of the digestate and the lowered biological oxygen demand relative to organics digested in an open lagoon.[36] This is a serious concern as N_2O is a powerful GHG with approximately 250 times the GWP of CO_2. Including N_2O in net GHG calculations is important to understanding the full climate benefit of manure methane reduction projects. (For further discussion see Box 6.)

BOX 3: INTEGRITY ISSUES WITH USE OF DEFAULT VALUES FOR QUANTIFYING MANURE-RELATED BASELINE AND PROJECT EMISSIONS

Regarding the parameters involved in the calculation of the baseline and project methane emissions, these vary widely between mechanisms and methodologies. However, there are some parameters that are key in estimating methane emissions from manure characteristics and management activities and are therefore considered in most of the analyzed methodologies.

The use of default values is common to all manure management methodologies. This raises several issues that can impact the uncertainty of the baseline and project emissions, which can lead to over- and under-estimation of emissions reductions. Applicable examples for project activities covered by the assessed manure management methodologies are provided below.

Manure management parameters where default values are specified:

- MCF = Annual methane conversion factor
- B_o = Maximum methane producing potential/capacity of the manure by livestock category
- VS = Amount of volatile solid in manure by type of animal
- Methane leakage from anaerobic digesters/reactor
- Direct N_2O emissions factor for composting (in kg N_2O -N/kg N)
- Emissions factor for indirect N_2O emissions from atmospheric deposition of nitrogen
- Emissions factor for indirect emissions of N_2O from runoff
- Fraction of total nitrogen that volatizes as ammonia and N_2O

The use of default values could impact the estimation of emissions reductions in several ways:

- Introducing uncertainty: Default values are intrinsically uncertain; For example, the IPCC default estimates of Bo have an uncertainty of ±15%.[37] The uncertainty related to two separate default values which are used in the same formula (e.g., Bo and VS) will lead to a combined uncertainty, which will be greater than the individual uncertainties.
- Non-standardization across crediting programs: When different methodologies use different default values for the same parameter, this can run the risk of creating credits that are not equivalent or even comparable. Differences in the way credits are derived under different methodologies may result in project developers and buyers focusing on securing the greatest number of credits for the least amount of investment, which risks pushing methodologies with the highest standards out of the market. The more standardization there is between methodologies for similar project types, the more confident marketplace stakeholders can be that credits are equivalent and represent as close to one ton of avoided or reduced CO_2e as possible.

- Over- and under-estimation of emissions impact: The conservativeness of some of the default values may lead to over- and under-estimation of baseline and project emissions reductions. For instance, the IPCC suggests a conservative default value of 10% methane leakage from anaerobic digesters/reactors when site or system-specific data is not available.[38] This level of discounting is high compared to recent studies that have shown that leakage could be less than even 3% on average.[39]



Key Takeaways:

- There is a need to undertake research to provide default values with lower uncertainty.
- Default values tend to have an inherently higher uncertainty compared to parameters that are monitored.
- Improved default values should provide a level of granularity that reflects the diversity of conditions and operating practices found at national or regional level.
- Where tiered IPCC default values are used, Tier 2 regional values are a minimum best practice, versus Tier 1 global values. Tier 3 farm-level values are typically not easily accessible.
- If default values for emissions factors are not conservative, such as Tier 1 global values, discount to correct for over-estimation of emissions reductions. For example, only approve 90% of estimated reductions.

FIGURE 3: TIER METHODOLOGICAL COMPLEXITY

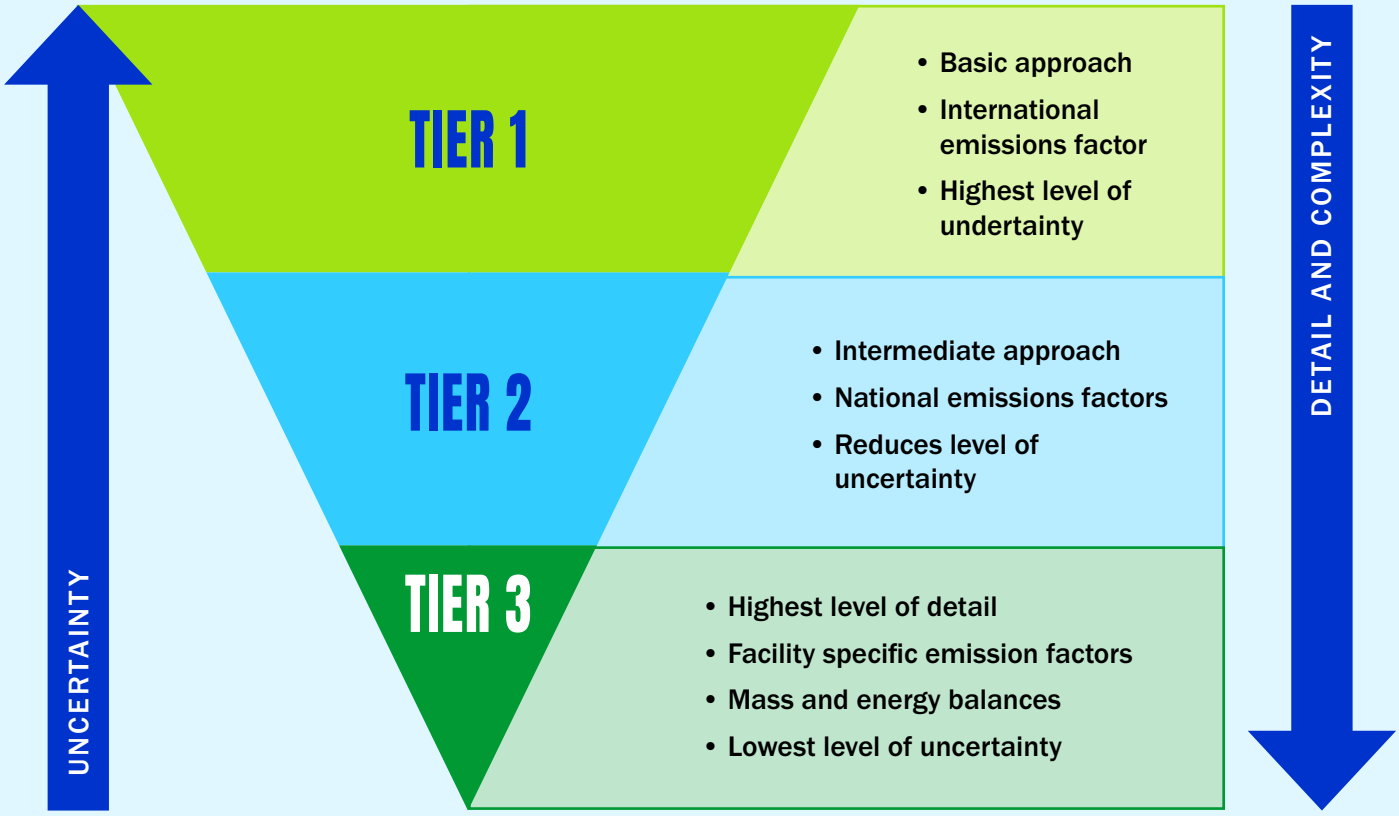


Image Source: Agrecalc, Booysen et al., 2018. https://www.agrecalc.com/home/insights/ipcc-tier-2-methodology-agriculture-carbon-footprint/

Table 6 provides a summary of the main differences in approaches throughout methodologies with respect to determining baseline and project emissions for the reviewed manure methane related methodologies.

TABLE 6: APPROACHES TO DETERMINING BASELINE AND PROJECT EMISSIONS THROUGHOUT THE MANURE METHANE RELATED METHODOLOGIES

Methodology	Prescribed approaches to determine baseline and project emissions	Estimation of upstream and/or downstream emissions required	Estimation of net GHGs
Gold Standard: GHG emissions reductions from manure management systems and municipal solid waste	On-site measurements or IPCC Tier 2 method	Upstream: manure/ waste residue transportation and storage Downstream: residue from anaerobic digester composting	CH_4, N_2O: direct and indirect emissions from manure waste stream treatment processes CO_2: manure transportation and energy use
Gold Standard: Animal manure management and biogas use for thermal energy generation	IPCC 2019 Tier 1 or Tier 2 method	Upstream: Manure production, collection and transport Downstream: fuel production and transport, thermal energy delivery	CH_4, N_2O: manure treatment process and residue from anaerobic digester composting, fuels combustion CO_2: energy generation and use
Climate Action Reserve: U.S. livestock project protocol V4.0	On-site measurements or default values for various parameters provided by IPCC, EPA and other sources	Upstream: manure production, collection and transport Downstream: vehicle emissions for land application and off-site transport	CH_4, CO_2: mobile and stationary combustion
California's Low Carbon Fuel Program: Low carbon fuel standard regulation	Modeled baseline Project emissions: On-site measurements and factors from the CA-GREET 3.0 model	Upstream: manure production, collection, and transport Downstream: vehicle emissions for land application and off-site transport	CH_4, CO_2: mobile and stationary combustion

Methodology	Prescribed approaches to determine baseline and project emissions	Estimation of upstream and/or downstream emissions required	Estimation of net GHGs
California's ETS: Capturing and destroying methane from manure management systems	Modeled baseline: default emissions factors and equations provided Project emissions: on-site measurements	Upstream: manure production, collection and transport Downstream: vehicle emissions for land application and off-site transport	CH_4, CO_2: mobile and stationary combustion
U.S. EPA: Renewable fuel standard program	Energy Independence and Security Act determines and mandates a 2005 petroleum baseline Life cycle emissions of fuels modeled based on IPCC Tier 1 method	Upstream: manure production, collection and transport Downstream: Fuel transport and use	All gasses involved in the life cycle: CH_4, CO_2, HFCs, SF6, N_2O, PFCs
U.S. Regional Greenhouse Gas Initiative: Model offset consistency applications and model monitoring and verification reports	Direct measurements and default emissions factors for CO_2 emissions from transport	Upstream: manure transportation Downstream: effluent management	CH_4, CO_2: transportation
Alberta: Quantification protocol for biogas production and combustion	Direct measurements and estimated parameters	Downstream: digestate management, end-use combustion of biogas	CH_4, CO_2, N_2O
U.N. Clean Development Mechanism, AMS-III.R.: Methane recovery in agricultural activities at household/small farm level	Field surveys and IPCC Tier 1 or Tier 2 method	No	CH_4

Methodology	Prescribed approaches to determine baseline and project emissions	Estimation of upstream and/or downstream emissions required	Estimation of net GHGs
U.N. Clean Development Mechanism, AM0073: GHG emissions reductions through multi-site manure collection and treatment in a central plan	Direct measurements and use of IPCC guidelines and default values	Upstream: manure transportation Downstream: sludge composting	CH_4, CO_2: electricity and fuel use N_2O: manure treatment processes and sludge composting
U.N. Clean Development Mechanism, ACM0010: GHG emissions reductions from manure management systems	Direct measurements and IPCC guidelines and default values	No	CH_4, CO_2: electricity and fuel use N_2O: manure treatment process and sludge composting
U.N. Clean Development Mechanism, AMS-III.D.: Methane recovery in animal manure management systems (Small Scale)	Direct measurement of the quantity of manure treated together with its specific volatile solids content or IPCC Tier 2 method	Upstream: manure transportation	CH_4, CO_2: fossil fuels or electricity used for the operation of all the installed facilities and transport
U.N. Clean Development Mechanism, AMS-III.Y: Methane avoidance through separation of solids from manure treatment system	Total mass of the volatile solids separated determined through historical records	Upstream: manure transportation	CH_4, CO_2: fossil fuels or electricity used for the operation of all the installed facilities and transport
Australia: Animal effluent management	Regional default values	Downstream: treatment of diverted material	CH_4, CO_2 and N_2O

Monitoring Requirements

The monitoring requirements of any methodology will have a significant impact on the quality and uncertainty of the emissions reduction estimates.

For example, direct measurements should lead to lower uncertainty compared to estimates based on the use of default values. However, current direct measurement methodologies must be validated and standardized to obtain precise and accurate measurements. Monitoring frequency (e.g., weekly, monthly, annually or continuously) may also impact the uncertainty of the estimates, where less frequent monitoring offers fewer data points to capture variability. Cost and technology needs may, however, determine which options can be used.

Some of the assessed methodologies provide a comprehensive monitoring system focused on technical parameters, whereas others use a simpler monitoring system, based on aggregated technical parameters and operational records.

ENTERIC METHANE EMISSIONS MONITORING REQUIREMENTS

Although there are significant similarities with respect to the parameters to be monitored across the 11 enteric methane reduction methodologies, there are also differences related to the number of parameters to be monitored, the origin of the data and the frequency of monitoring. This may lead to different estimated emissions reductions reported across mechanisms for the same technologies or practices, impacting the equivalency of carbon credits across crediting programs, and even across methodologies within the same program. Table 7 summarizes the approaches taken for monitoring by the reviewed methodologies.



TABLE 7: APPROACHES TO CALCULATING BASELINE AND PROJECT EMISSIONS AND MONITORING REQUIREMENTS FOR ENTERIC METHANE REDUCTION METHODOLOGIES

Methodology	Approach to calculating baseline and project emissions	Monitoring frequency
Gold Standard: Reducing methane emissions from enteric fermentation in dairy cows through application of feed supplements	(i) On-site measurements or (ii) Regression models **or** IPCC Tier 2 equations integrating data from peer-reviewed publications	Annual
Gold Standard: Methodology for quantification of GHG emissions reductions from improved management in smallholder dairy production systems using a standardized baseline	Based on IPCC default values (Tier 2)	Annual
Gold Standard: Methane emissions reduction from enteric fermentation in beef cattle through application of feed supplements	(i) On-site measurements or (ii) Regression models **or** IPCC Tier 2 equations integrating data from peer-reviewed publications	Annual
Verified Carbon Standard: Methodology for the reduction of enteric methane emissions from ruminants through the use of feed ingredients	Baseline: (i) on-site measurements or (ii) IPCC default values Project emissions: enteric methane emissions reduction factor determined through (i) on-site measurements or (ii) peer reviewed meta-analysis	Mainly annual, some monthly depending on parameter
Canada's GHG offset credit system: Reducing Enteric Methane Emissions from Beef Cattle (Draft)	Based on IPCC default values (Tier 2) and regional default values	Annual or by feeding period, depending on parameter
Alberta Carbon Offset Program: Quantification protocol for selection for low residual feed intake in beef cattle	Based on IPCC default values (Tier 2)	Continuous or annual depending on parameter

Methodology	Approach to calculating baseline and project emissions	Monitoring frequency
Alberta Carbon Offset Program: Quantification protocol for reducing greenhouse gas emissions from fed cattle	Based on IPCC default values (Tier 2)	Continuous or annual depending on parameter
U.N. Clean Development Mechanism, AMS-III.BK.: Strategic feed supplementation in smallholder dairy sector to increase productivity	Based on IPCC default values (Tier 2)	Annual
Australian Emissions Reduction Fund: Reducing emissions by feeding dietary additives to milking cows	Based on regional default values	Annual or by feeding period, depending on parameter
Australian Emissions Reduction Fund: Reducing emissions by feeding nitrates to beef cattle	Based on regional default values	Annual or by feeding period, depending on parameter
Australian Emissions Reduction Fund: Beef cattle herd management	Based on regional default values	Annual or by feeding period, depending on parameter

Measurement procedures used to quantify the indicators used in modeling of enteric methane emissions vary and are specific to the parameter being monitored.

No methodologies require direct measurement of methane emissions, however, VCS and Gold Standard's (feed additives) enteric methane-related methodologies allow users to directly measure emissions as one of the reporting options. Examples of measurement procedures include:

- Counting the productive females on the producer's farm (UNFCCC CDM).
- Determining weight using heart-girth measurement (UNFCCC CDM).
- Interviews with herd producer (UNFCCC CDM).
- Site-inspection of the dairy farm and surveys conducted by the project proponent according to International Organization for Standardization (ISO) 14040 and 14044. Feed suppliers should also report the standard error of the mean to allow quantification of uncertainty (Gold Standard).
- Use of default values sourced from recognized, credible sources and geographically and temporally relevant to the project context. These values must be based on well-documented, reliable sources. The range of appropriate data must be documented, and the chosen data must be justified based on criteria such as data source, geography, technological specificity, conservativeness and the process by which the data have been peer-reviewed (preferred) (VCS).
- Discrepancies for prescribed monitoring/recording frequencies for the same or similar parameters are also evident, although most parameters are monitored on an annual basis, which is considered satisfactory by respective methodologies. For example, the frequency of monitoring of the daily dry matter intake ranges from annual (based on interviews with farmers) for the UNFCCC CDM methodology to "continuous" monitoring based on actual feed delivery records to each pen in the case of the Alberta methodologies.

It is important that methodologies use measurement procedures based on international standards such as ISO, and combined with models which will either lead to the lowest level of uncertainty, or to an estimate where the level of uncertainty is known and can be appropriately accounted for in the model.

BOX 4: INTEGRITY ISSUES WITH USE OF DEFAULT VALUES FOR QUANTIFYING ENTERIC METHANE BASELINE AND PROJECT EMISSIONS

The use of default values is common to all enteric methane reduction methodologies, raising several issues which can impact the uncertainty of the baseline and project emissions and therefore the estimation of emissions reductions. Examples that can be applicable to the project activities covered by the assessed enteric methodologies are provided below.

- Ym (%) = Conversion factor indicating the proportion of gross energy intake through feed converted to enteric methane energy; energy as a percentage of gross energy
- Global warming potential (GWP) of methane (t CO_2e/t CH_4) over 100-year time horizon
- Average energy content of dry matter
- Average enteric methane emissions factor

The use of default values could impact the estimate of emissions reductions in several ways:

- The intrinsic uncertainty of the default value: For example, the IPCC estimates of Ym (%) used as defaults have an uncertainty of >30% for certain livestock categories.[40]
- In general, the high level of uncertainty is managed in the methodologies by selecting conservative default values. In this context, a conservative default value is one which is either at the upper or lower limit of the range of uncertainty for the specific value, which will result in either an estimation of baseline emissions at the high end of the range and/or an estimation of project emissions at the low end of the range. This is intended to lead to an estimation of emissions reductions at the low end of the range.
- A combined uncertainty which is usually greater than the individual uncertainties when two separate default values are used in the same formula.
- The use of different default values for the same parameter: For example, our analysis shows that the default value for "fraction of gross energy in feed converted to methane (Ym, %)," which is critical to the estimation of methane emissions per animal, ranges from 4% to 7.5% between different methodologies. This highlights that completely different estimates of methane emissions per animal could be calculated for the same feed with the same energy content, and which could vary by nearly 90%.
- The GWP used could also be a source of discrepancy with regard to defaults used, as some methodologies refer to the IPCC Fourth Assessment Report, where a 100-year GWP of 25 is specified for methane, whereas others refer to the "most recent IPCC report," which is the Sixth Assessment that proposes a 100-year GWP of 27.2 for non-fossil fuel methane.

- Where emissions from manure are included in the project boundary, default values listed under manure management may also apply (see Box 3).
- The use of proxy "parameters:" For example, heart-girth measurement to determine animal weight, may introduce uncertainty compared to direct measurement of animal weight. Although the literature on this specific item suggests that heart-girth measurement provides a relatively accurate estimation of weight, the use of this method in the field and outside of research conditions may increase uncertainty. [41,42]
- Based upon the current understanding of enteric methane emissions, data inputs for variables across the full lifecycle of emissions that influence rumen activity, which results in enteric methane emissions and manure-related emissions should be sourced from farm-specific data to best estimate emission reductions from the use of enteric methane reduction interventions.[43] These variables include animal type, genetics, gestation/lactation stage, nutrient inputs, output of animal products, management of feeding operations, confinement conditions, manure handling practices, physical characteristics of the site, and climate and weather conditions. Use of regional or global average input values instead of farm-specific data will introduce more uncertainty than those based upon farm-specific inputs. This uncertainty should be managed by using conservative values to avoid overestimating methane reductions.

Key Takeaways:

- There is a need to undertake research to provide default values with lower uncertainty and farm system specificity.
- Default values tend to have an inherently higher uncertainty compared to parameters which are monitored. Improved default values should provide a level of granularity which reflects the diversity of conditions and operating practices found at national or regional levels.
- Where IPCC defaults values are used, best practice to improve data accuracy should always be to use Tier 2 (regional) values as a minimum, and Tier 1 (global) values where this cannot be avoided. For both, emissions reductions may need to be discounted to correct for high uncertainty and help ensure conservative estimates.
- If default values for emissions factors are not conservative (i.e., Tier 1 global EFs), discount to correct for over-estimation of emissions reductions (e.g., only approve 90% of estimated reductions).

MANURE METHANE EMISSIONS MONITORING REQUIREMENTS

There are similarities between the parameters that are monitored for manure management, and most of the methodologies are based on the monitoring system established by the CDM. There are, however, differences related to the number of parameters to be monitored, the origin of the data and the frequency of monitoring which may lead to different estimated emissions reductions reported across mechanisms for the same technologies or practices. Table 8 below provides a summary of monitoring approaches determined by the assessed methodologies.



TABLE 8: APPROACHES TO MONITORING REQUIREMENTS THROUGHOUT THE MANURE-RELATED METHODOLOGIES`

Methodology	Source of data	Monitoring procedure	Monitoring frequency
Gold Standard: GHG emissions reductions from manure management systems and municipal solid waste	Direct measurement using flow meters IPCC, data from project proponents, studies and official reports	Mix of measurements and estimates	Depending on a parameter, continuous, weekly, monthly or annually
Gold Standard: Animal manure management and biogas use for thermal energy generation	Country specific, IPCC, methodology specific default, IPCC Assessment Reports (AR 4 and 5), project specific measurements at randomly selected project sites, credible published literature for the project area	Mix of measurements and estimates	Every two years, annual, monthly continuous
Climate Action Reserve: U.S. livestock project protocol V4.0	Direct measurement using flow meters Default values, values from operating records, measurements	Mix of measurements and estimates	Depending on a parameter, continuous, weekly, monthly or every reporting period

Methodology	Source of data	Monitoring procedure	Monitoring frequency
California's Low Carbon Fuel Program: Low carbon fuel standard regulation	Direct measurement using flow meters Administrative and non-technical data	Monitors parameters related to the identification and traceability of fuels, in order to make a simple estimate of emissions reductions and credits generated. Monitors data on credits transactions	Quarterly or annually, depending on a parameter
California's ETS: Capturing and destroying methane from manure management systems	Operating records, default values, direct sampling, measurements	Mix of measurements and estimates	Most parameters are monitored on a monthly or weekly basis
U.S. EPA: Renewable fuel standard program	Direct measurement using flow meters; Operating records	Monitoring system is voluntary	Continuous, quarterly or annually, depending on a parameter
U.S. Regional Greenhouse Gas Initiative: Model offset consistency applications and model monitoring and verification reports	Direct measurement using flow meters; Operating records	Mainly measured	Monthly
Australia: Animal effluent management	Direct measurement using flow meters, administrative documents (invoices, records, etc.)	Mainly measured	Continuous
Alberta: Quantification protocol for biogas production and combustion	Direct measurements using flow meters, default values from IPCC, studies and official reports	Mix of measurements and estimates	Most parameters are monitored on a monthly or weekly basis

Methodology	Source of data	Monitoring procedure	Monitoring frequency
U.N. Clean Development Mechanism, AMS-III.R.: Methane recovery in agricultural activities at household/small farm level	Default values for some parameters, operating records, measurement campaigns at randomly selected sample sites	Mix of measurements and estimates	Once only, monthly, annually or biennially, depending on a parameter
U.N. Clean Development Mechanism, AM0073: GHG emissions reductions through multi-site manure collection and treatment in a central plant	Default values from IPCC, direct measurements of pipe flow or flow meters, data from operating records	Mix of measurements and estimates	Daily, weekly, monthly or annually, depending on a parameter
U.N. Clean Development Mechanism, ACM0010: GHG emissions reductions from manure management systems	Direct measurement using flow meters, default values from IPCC, direct measurements, data from operating records	Mix of measurements and estimates	Daily, weekly, monthly or annually, depending on a parameter
U.N. Clean Development Mechanism, AMS-III.D.: Methane recovery in animal manure management systems (small scale)	Default values from IPCC or nationally published sources, farm records, direct measurement using flow meters	Mix of measurements and estimates	Daily, weekly, monthly or annually, depending on a parameter
U.N. Clean Development Mechanism, AMS-III.Y: Methane avoidance through separation of solids from manure treatment systems	Farm records and direct measurements (i.e., of manure solids content)	Mix of measurements and estimates	Daily (number of animals) or annually; all other parameters

BOX 5: WHY MEASURING EFFICACY IS SO IMPORTANT FOR ENTERIC METHANE REDUCTION SOLUTIONS

Science-based, data-driven evidence of the efficacy of various enteric solutions is critical for being able to generate credits that accurately represent GHG reductions. The efficacy of enteric methane reduction solutions may be influenced by several factors, including dose, diet, production system, type of animal, the stage of the animal's life seasonality, cow well-being or comfort, and random variation. Given the challenges with measurement methodologies and many factors that can impact the efficacy of solutions, standard guidelines for assessing the efficacy of feed additives for enteric methane reduction and mitigation strategies should be established to have confidence in the measurements and allow comparison between solutions.

Requirements for the evidence needed to demonstrate efficacy need to be stronger than they currently are in any of the methodologies. For instance, cited peer-reviewed publications need to provide evidence as to the magnitude of emissions reductions. Additionally, the reviewed methodologies have inconsistent qualifying requirements for proving enteric methane-reducing solutions' efficacy. The reviewed methodologies use varying methods to determine enteric methane emissions reductions following solution implementation, all of which impact the accuracy of project emissions calculations. These include:

- Internationally or nationally determined default values, such as IPCC's emissions reduction factors.
- Solution-specific emissions reduction factors provided by the manufacturer of the product-based solution for which credits are generated, established through meta-analysis of peer-reviewed publications.
- Directly measuring enteric methane production per animal group per day while consuming the feed additive during the monitoring period, then using those direct measurements to determine an estimated emissions reduction factor for each animal group.

Four methodologies include requirements for project proponents to submit evidence of the efficacy of enteric methane-reducing solutions to demonstrate initial project eligibility:

- **Gold Standard's Feed Supplement methodology for dairies:** Specifies in the applicability conditions that the feed supplement applied shall have proven efficacy of emissions reductions in in-vivo application with dairy cattle published in peer-reviewed scientific literature.

- **Gold Standard's feed supplement methodology for beef:** Specifies that the feed additive applied shall have consistently proven efficacy of emissions reductions in in-vivo application with beef cattle published in peer-reviewed scientific literature. The data shall quantify the specific supplement's emissions reductions and define applicability of the data, especially dependencies on diet and additive application, animal type, age and weight, environmental and management conditions as well as any other factors that could impact the supplement's emissions reductions performance.

- **U.N. CDM's AMS-III.B.K. methodology for strategic feed supplementation in smallholder dairy sector to increase productivity:** Specifies in the applicability conditions that the gross energy (GE) content of the supplement consumed shall not exceed 10% of the total GE content of the basal ration per stage of lactation for each of the respective baseline production categories, to ensure that the supplement will indeed increase milk productivity through enhanced digestibility.

- **VCS' methodology for the reduction of enteric methane emissions from ruminants using feed ingredients:** Specifies in the project emissions reduction factor section that a meta-analysis of at least three peer-reviewed publications from reputable journals (listed in the Science Citation Index Expanded) is required. The efficacy of feed additives is influenced by the factors listed above. Therefore, a meta-analysis that considers these factors is necessary to obtain efficacy estimates within the range of the data used for the meta-analysis. The conditions of the project must not deviate greatly from the conditions under which the enteric methane emissions reduction factor is determined in the meta-analysis of published results.

- **Canada's Greenhouse Gas Offset System:** Reducing Enteric Methane Emissions from Beef Cattle (Draft): The protocol specifies that "If the eligible project activity is modifying or adjusting the dosage of a feed additive, sign-off must be provided from a qualified professional indicating the newly prescribed dosage is expected to improve the GHG emissions intensity of the project as quantified" by the given methodology.

Once project proponents demonstrate project eligibility by meeting the criteria listed above, the efficacy of the intervention is further evaluated through site visits, 3rd party verification and registry review of all submitted information.

For the remaining six out of 11 enteric methane reduction methodologies, it is unclear how the programs reviewed the scientific literature on the efficacy of each enteric methane reduction practice when putting together the quantification methodologies.[44]

Across all 11 enteric methane reduction methodologies, the requirements to prove efficacy have the following areas for improvement:

- A lack of detail on meta-analyses of peer-reviewed scientific literature, which is deemed acceptable as proof of efficacy, or if there is a minimum number of citations needed.
- A lack of guidelines on how to assess the applicability of study results to the specific project activity.
- Quantification methodologies which include assumptions that could negatively impact the accuracy of project emissions calculations.
- Assumption that farmers will be able to consistently deploy feed additives under certain conditions. For instance, some methodologies require the feed additive be used as per the manufacturer-provided feeding instructions, which can be multiple times per day. The instructions must also define the critical conditions needed to secure the default level of reduction in enteric methane emissions, such as the feeding routine and dose of ingredient per kilogram of dry matter intake by the animal.

Key Takeaways:

- Requirements for demonstration of efficacy throughout the methodologies need to be strengthened and standardized.
- If no guidelines are provided on how to assess the applicability of study results to the specific project activity, this could have a significant impact on the validity of the data used under various iterations of the product and the feed environment, type of livestock and management of the animals (e.g., if research was conducted with animals who are fed a specific feed ratio, then the results may not be applicable on a farm where animals are fed according to a different feeding regimen).
- For methodologies that credit for a single intervention with an assumed efficacy and therefore do not have efficacy requirements for project developers, there should be enhanced transparency around how the program evaluated the efficacy of solution(s).
- When methodologies allow the use of solution-specific emissions factors (EFs), rather than the feed additive manufacturer providing the EFs, they should be independently recommended, reviewed and approved by a neutral third-party group of experts.

Leakage

The term leakage is used in two ways:

1. The so-called "rebound effect," or systemic leakage, occurs when some of the potential emissions reductions from a mitigation activity are canceled out by increases in emissions due to changes in behavior because of that activity outside (upstream/downstream) the project boundary and...

2. The physical loss of methane to the atmosphere from within the project boundary, which we refer to here as project leakage.

ENTERIC METHANE LEAKAGE

Sources of project-level emissions leakage for enteric methane emissions may include:

- Activities that reduce emissions from enteric fermentation may lead to impacts on the quantity and quality of the manure produced, which would lead to a change in emissions from downstream manure management due to the project activity.
  - All methodologies except the UNFCCC CDM methodology include changes in GHG emissions from manure quantity and/or decomposition due to the project activity (Table 8).
- Production of the feed additive itself may lead to additional upstream GHG emissions compared to the baseline scenario as well.
  - Some methodologies consider emissions from the production of the feed additive.
- Reduction of project-specific herd size can lead to the increase in off-site herd size to fill the market gap in other regions of the globe.

Table 13 in the appendix details how some of the methodologies consider leakage beyond the project boundary, or systemic leakage. Positive economic impacts from these project types could be re-invested in expansion of herds, which may therefore lead to increased emissions. However, the likelihood and impact of this behavior is not known.

MANURE LEAKAGE

Systemic leakage from manure management may refer to methane and N_2O emissions from the application of treated manure to land and CO_2 emissions from manure transport.

- Nine out of 14 methodologies set explicit requirements for project developers to assess potential on-site leakage that may result from the project activities, whereas the remaining methodologies do not address systemic or on-site leakage.

Project leakage can occur from:

- The equipment used to treat the manure.
- Methane that escapes from anaerobic digesters through lack of upgrading corroded materials or through general openings that allow leaks (biogas is very corrosive).

Only a few methodologies explicitly require project developers to assess potential systemic leakage emissions that may result from the project activities.

- The VCS methodology concludes that any changes in animal performance would be minimal and would not justify the costs and risks of increasing or decreasing animal numbers.
- It could be argued that any positive economic impacts from these project types could be re-invested in the expansion of herds, which may therefore lead to increased emissions, but the likelihood and impact of this eventuality is not known.

Table 13 in the appendix details how some of the manure methodologies consider leakage beyond the project boundary, or systemic leakage.



Sustainable Development Benefits and Safeguards



Following ICVCM CCPs, we explored how programs that facilitate crediting for avoided livestock methane emissions adhere to transparent stakeholder consultation processes, social and environmental safeguards, sustainable development benefits, and the principle of no net harm. Carbon crediting programs shall have clear guidance, tools and compliance procedures to ensure mitigation activities conform with, or go beyond, widely established industry best practices on social and environmental safeguards while delivering positive sustainable development impacts.

Carbon marketplaces are trading systems that allow some participants to profit from reducing their emissions by selling the emissions reduction to another sector, leaving them with no claim over the reduction. While this is a powerful tool for incentivizing and scaling emissions reductions efforts, there are also risks that need to be considered. Part of ensuring that carbon markets scale with integrity is ensuring that these markets help support equitable and just outcomes for participants and for all the stakeholders of livestock systems.

Carbon markets should not add to or exacerbate existing socioeconomic and environmental inequities.



This will require carbon market participants and registries to integrate the following concepts of equity, environmental justice and just transition in their transactions and market regulations:



Equity is achieving fairness and balance in access to environmental resources (e.g., green space, safe neighborhoods, healthy homes, healthy fisheries), bearing environmental burdens (e.g., pollution in air, water and on land), and participating in environmental decision-making. Because we want to address an imbalance of benefits, this includes ensuring that payments within environmental markets are fairly distributed to stakeholders in those ecosystems. In the case of crediting for livestock methane reductions, equitable markets are ones that fairly distribute profits from carbon projects to farmers, do not exacerbate local pollution and ensure community participation in relevant projects. Additionally, equitable markets should help lower barriers to farmer participation and encourage the participation of smaller farmers in markets.



Environmental justice is the belief that everyone, regardless of their race, income or social status, has the right to a clean, healthy environment and protection from environmental hazards. This involves equitable distribution of environmental benefits and burdens and meaningful participation of marginalized communities in environmental decisions, with a goal of restoration by addressing historical disparities. For carbon markets to support environmental justice, vulnerable communities who live near large livestock operations must be protected from the health impacts of large-scale agricultural production.



Just transition in this context is ensuring that the livelihoods of workers and impacted communities are prioritized as agricultural systems undergo necessary transformations to mitigate emissions or become “climate-smart.” In this context, farmers and farm workers must be supported in the transition to climate-smart practices and small producers should not lose their livelihoods attempting to bear the cost of emissions mitigation practices.

Historical systemic barriers have contributed to the disproportionate impact of climate change and environmental pollution on communities of color and low-income households.

Similarly, vulnerable and underserved communities also experience higher land and food insecurity. As a result, smaller farmers may have a hard time accessing the financial support necessary for continued food production and adoption of climate mitigation practices, including carbon market participation. Additionally, it is important for vulnerable communities who are located near large industrial livestock operations to have a say in how various carbon projects may impact their neighborhoods, whether through increased air pollution, water pollution or odor. For example, there are community concerns that large credit payments from carbon markets can create market distortions accelerating concentration of livestock operations and increasing local pollution impacts.[45] The use of offsets should not allow other environmental or health hazards to go unaddressed or worsen.

Social and environmental safeguards are important to ensuring that carbon projects avoid adverse environmental or social impacts on communities where the project is being implemented and that projects generate benefits for the environment and project communities beyond reducing GHG emissions, such as reducing air pollution.[46] Projects involving livestock operations can support equity and environmental justice through:

- Requiring assessments of environmental and social impacts for all projects
- Understanding and addressing the impact of livestock operations and manure management on local communities' health and environment
- Rigorously evaluating the impact of feed additives on animal and human health
- Supporting the poorest and most vulnerable affected by climate change through the inclusion of small-scale farmers and prioritization of a just transition

Requirements related to environmental and social impacts of emissions mitigation projects are typically provided at the crediting program level, rather than stated in each methodology within a crediting program. We found that carbon offset programs will instead include such requirements as part of the general eligibility criteria every project must satisfy. Among the analyzed mechanisms and methodologies, only a few explicitly require that emissions mitigation projects contribute to enhancing positive and preventing negative local environmental and social impacts (see Table 9).

TABLE 9: PROGRAM REQUIREMENTS TO ASSESS ENVIRONMENTAL AND SOCIAL IMPACTS

Standard	Requirement
Gold Standard	Project activities must directly contribute to at least three of the Sustainable Development Goals (SDGs).[47]
	Project activities must be in line with Gold Standard Safeguarding Principles and Requirements, which address impacts on human rights, gender equality, community health, safety and working conditions, environment, etc.
VCS	Project activities must directly contribute to at least three of the Sustainable Development Goals.
	Project activities must not harm either the natural environment or local communities or cause any potential negative environmental and socio-economic impacts; necessary steps to mitigate them are identified and addressed.
U.N. CDM	Project proponents must present an analysis of environmental impacts and specify whether the project activity was subject to an Environmental Impact Assessment.
CAR	Project proponents must demonstrate that their GHG projects will not undermine progress on other environmental issues such as air and water quality, endangered species and natural resource protection, and environmental justice.
Canada	The project site complies with all applicable federal, provincial, territorial, and municipal by-laws or regulations, including those related to the management of manure.
CA LCFS	None were accessible.
Alberta	None were accessible.
Australia	None were accessible.
U.S. EPA	None were accessible.
U.S. Regional Greenhouse Gas Initiative (RGGI)	None were accessible.

It is best practice that crediting programs have explicit requirements for social safeguarding and assessing environmental impacts. However, programs may also enhance positive environmental and social impacts through other means, such as designing methodologies that facilitate inclusion of small-scale facilities (see Table 10) and by requiring stakeholder consultations (see section below).

PROCEDURAL EQUITY: INCLUSIVE STAKEHOLDER CONSULTATION

Among the analyzed crediting programs, three include detailed provisions on stakeholder consultations (which includes environmental justice communities and other local community groups) at the project level: Gold Standard, VSC and the CDM. While stakeholder and public consultations on individual projects are only supported by these three "international" programs, national and/or government-led programs may also rely on other legislation with respect to stakeholder involvement. For example, under the Australian Emissions Reduction Fund, the projects related to land management (revegetation and savanna fire management) are required to comply with legislation that protects the interests of Indigenous Peoples. The Climate Action Reserve, being primarily designed for the U.S., refers to applicable regulations as primary means to protect local communities.

Beyond specific projects, the following programs also involve the public in the methodology and related standard setting process:

- Climate Action Reserve involves at least one public 30-day comment period with a public webinar for every new methodology development as well as every major methodology update, and all policy revisions.
- The VCS runs public consultations on new standards programs, program updates, new methodologies and updates to existing methodologies.
- Gold Standard rules require that any new program documents (including standards) are posted to the website, and the outcomes of any public consultation processes for proposed standards are published upon completion of consultation periods.
- Under the CDM, the submission of a proposed new methodology is posted publicly on the UNFCCC CDM website for global stakeholder consultation for 15 days.

Government-led state or national programs often use existing public consultation procedures that have been legally defined. For example, in California it is required by law that the state board adopts "rules and regulations in an open public process to achieve the maximum technologically feasible and cost-effective GHG emissions reductions." In the Alberta Emissions Offset System, the process of development and revision of methodologies requires a 30-day public comment period by law.

While public stakeholder review (inclusive of environmental justice communities and local community groups) of projects and standards is essential to ensuring equity within carbon market rule and decision-making processes, the requirement of a stakeholder review period alone is not sufficient. For example, simply posting a request for public comment on a carbon registries' website doesn't guarantee that key stakeholders within the community will be reached.

Rather, it is important for registries to actively engage key stakeholders, provide information in an easily accessible and understandable format, and provide sufficient time and space for in-person and virtual involvement with the process.

As a best practice, carbon registries should ensure that these processes are formalized through program policies that enforce free, prior and informed consent.[48]



BOX 6: WHY MANURE METHANE EMISSIONS MITIGATION ALONE IS NOT ENOUGH: UNDERSTANDING LOCAL ENVIRONMENTAL AND PUBLIC HEALTH IMPACTS ASSOCIATED WITH LIVESTOCK OPERATIONS

Investments in anaerobic digesters or covered lagoons alone for manure management do not sufficiently address a broader set of local environmental and public health impacts that can be associated with livestock operations. Digester effluent (digestate) is a byproduct of the anaerobic digestion process, which is often stored in uncovered basins. Treatment of digestate must also be managed to substantially reduce atmospheric emissions and protect local conditions, including both public health and environmental impacts. While capturing the methane contained within biogas reduces the global climate impacts of methane otherwise released during manure management, it may not reduce local pollution concerns and may result in emissions of other potent GHGs, which have serious local environmental and health impacts.[49]

Uncertainties around leakage of methane into the atmosphere.[50]

To provide climate benefits, renewable natural gas such as biogas from manure must result in a net reduction in methane emissions. Both the source of the organic materials digested to create biogas and the methane leaked during processing and transport for pipeline injection must be considered. Properly accounting for the counterfactual fate of selected organic sources for digestion/gasification for biomethane production is essential to generating an accurate number of credits.

In other words, how the organic material being digested is managed before a digester or other system is installed is important and is critical for determining if net methane emissions to the atmosphere are reduced.

- If the counterfactual treatment of the organic matter does not release methane to the atmosphere, then any methane leaked after digestion adds to the net methane emitted to the atmosphere.
- Where anaerobic digesters are diverting manure from currently digested manure in open treatment systems, the captured methane is avoiding a current loss and reducing net methane emissions to the atmosphere. If the organic material such as grasses or wood that are being digested/gasified to produce methane is not currently producing methane, then any methane lost because of digestion/gasification is adding to the net methane emitted to the atmosphere. This means it is not likely to be providing a climate benefit, even if it is offsetting fossil natural gas or other fossil fuels.

Alvarez et al., (2018) estimates that a net methane loss rate of about 3% negates the climate benefits of replacing fossil natural gas with biogenic methane for at least a couple of decades, which is why leakage in digester systems needs to be further studied. Additionally, other pollutants emitted by these operations need to be addressed.

The high concentrations of ammonium in the digestate will likely also result in ammonia emissions that are either equal to, or greater than, the ammonia emissions from an open lagoon prior to the installation of the anaerobic digester (i.e., the counterfactual). Little is currently known about the levels of ammonia (and N2O) emissions from secondary lagoons storing digestate, but this needs to be better understood. Even if it is determined that ammonia emissions levels are not higher in a secondary lagoon storing the digestate from an anaerobic digester relative to those measured in a primary lagoon, the current levels of ammonia released from farms that store manure in an open lagoon are still a concern and can have negative environmental and social impacts due to its ability to form fine particulate matter, which can cause serious health consequences.

Key Takeaways:

- Understanding levels of leakage throughout the biogas upgrading system is critical to accurately accounting for emissions reductions.
- There is a need for further research into ammonia and N_2O emissions from the digestate to understand the true net benefits of digester technologies.
- When installing digesters, there should be robust community engagement to understand the community's pre-existing concerns and priorities, particularly if they are associated with livestock operations, and to develop effective responses to those concerns, including treatment, monitoring and disclosure of local pollutants.
- Digester technology should include appropriate digestate treatment system(s) to reduce ammonia emissions, without increasing N_2O emissions; regardless of whether ammonia emissions are the same or higher than from digestion in an open lagoon.

EQUITABLE ACCESS FOR SMALLHOLDER FARMERS TO PARTICIPATE

Three methodologies within the CDM and Gold Standard target projects at small-scale facilities or in developing countries. As a result, project activities are implicitly required to contribute to positive social impacts by supporting vulnerable populations that are on the frontlines of climate change (see Table 5). Reviewed methodologies that did not have publicly available guidelines for this criterion are not included in the table below.

TABLE 10: GOLD STANDARD AND CDM METHODOLOGIES THAT FOCUS ON SMALL-SCALE FACILITIES

Methodology	Scale	Requirements
U.N. CDM AMS-III. R	Individual households or small-scale farms	Domestic biogas digesters/methane recovery systems that achieve an annual emissions reduction of less than or equal to five tonnes of CO_2e GWP100 per system
U.N. CDM AMS-III.BK - Strategic feed supplementation in smallholder dairy sector to increase productivity	Small-scale farms	Animal population equal or less than 100 heads per farm
Gold Standard Improved Management in Smallholder Dairy Production Systems	Smallholder dairy systems	Smallholders are farmers that have more than 50% of farm work done by family members, cooperative members or neighbors

The CDM methodologies also allow for aggregation within a "programme of activities" (PoA), which makes it possible to register the coordinated implementation of a policy, measure or goal that leads to emissions reduction. Under a PoA, multiple small farms can participate in a single program, and once a PoA is registered, an unlimited number of smaller projects under the same methodology can be added without undergoing the complete CDM project cycle.

Currently, many of the existing methodologies are only feasibly implemented at a large scale where enough credits will be generated to cover large up-front investments and highly complex MMRV requirements for projects. This means that it is currently not feasible for small farmers to participate in many of the methodologies included in this report.

However, a PoA allows multiple farmers to participate in a single project, helping the project achieve scale and reduce the reporting requirements an individual farmer must adhere to.

This system helps enable the just transition by ensuring that more of the world's small and vulnerable farmers can participate in carbon markets and be rewarded for their mitigation efforts.

The CDM also allows multiple methodologies and therefore multiple measures or technologies to be covered by a single PoA. A single PoA could therefore include measures targeting both enteric fermentation and manure management. Gold Standard and VCS also recognize CDM methodologies and PoAs.



Recommendations



The measures outlined in this report to reduce methane emissions face several financial and technical barriers to their widespread implementation. The generation and transaction of carbon credits provide a possible revenue stream that can contribute to overcoming these barriers. The generation and transaction of carbon credits can be leveraged to drive some of the funding needed to reduce methane from livestock systems to the global agriculture system. Credits from livestock methane reductions represent permanent emissions reductions and have relatively high additionality compared with other credit types — qualities that can help differentiate them to interested buyers.

Approval by the ICVCM should be considered a first step to ensuring that credits are high integrity. Beyond this, programs should continue to regularly update methodologies to achieve high-quality credits.

The variety of possible crediting programs and their distinct methodologies may lead to confusion and reticence on behalf of farmers, project developers and buyers of carbon credits. This report seeks to address this by providing a high-level assessment of the current methodologies and mechanisms and their key differences. Crediting programs that prioritize the continuous improvement of existing livestock methodologies can further differentiate themselves as high-quality in a competitive marketplace.

To facilitate this continuous improvement, we have highlighted four major recommendations:

1. Undertake research to provide higher quality, with lower uncertainty, emissions reduction default values to more accurately quantify projects' emissions impacts for both enteric and manure methodologies.

2. Establish guidelines and best practices for assessing the applicability of scientific evidence for the safety and efficacy of feed additives in the project setting and to ensure that quantification methodologies are regularly updated as additional data becomes available.

3. Fill research gaps related to full GHG accounting for manure management projects, especially for manure digester projects.

4. Institute and/or strengthen program requirements aimed at protecting local communities, going beyond regulatory requirements where needed.

These recommendations are further broken out below into actions that can be taken by carbon-crediting programs, standards bodies and the scientific community to improve the integrity of credits generated from livestock projects.

Carbon-Crediting Programs

The following recommendations outline actions that carbon-crediting programs can take to help build confidence and reduce uncertainty with respect to carbon credits generated from methodologies targeting livestock GHG emissions. For both enteric and manure methodologies:

Move towards more standardized default values for parameters used across methodologies and prioritize regular updates of emissions factors in methodologies based on best-available research.

The extensive use of default values is common to all methodologies. The source of these default values and the uncertainty associated with them may have a significant impact on the estimate of emissions baselines and project emissions reductions. The use of default values from different sources for the same parameter in different methodologies both adds to the uncertainty and may lead to different estimated emissions reductions reported across mechanisms for the same technologies or practices. Increased standardization and robustness of default values and parameters across methodologies would improve credit equivalency across programs and improved accuracy of credits generated.



FOR ENTERIC METHODOLOGIES

Ensure emissions factors for feed additives undergo sufficient academic review.

If enteric methane emissions baselines and reductions over time are derived by applying an empirical emissions factor (EF), rather than by using data from on-site direct measurements, those EFs should be recommended, reviewed and approved by a neutral third-party group of experts. It is not sufficient, for example, to have the EF provided by the feed additive manufacturer with a meta-analysis of at least three peer-reviewed studies as some protocols currently require. The studies could be chosen to put the product in a certain favorable light and overlook evidence of negative effects and may not reflect the actual performance to be expected with a contributing farm. Criteria for a robust meta-analysis is needed to provide a valid picture of the current state of the science.

Ensure a sufficient burden of proof needed for feed additives to gain project eligibility.

Feed additives aimed at reducing enteric methane emissions have demonstrated varying degrees of efficacy and safety for both animals and humans. Most methodologies assessed do not evaluate potential animal health and human food safety impacts as independent criteria. Some methodologies establish regulatory approval as a criterion for qualification. However, regulatory treatment of enteric feed additives for enteric methane reduction varies among jurisdictions. For example, products claiming environmental benefits and mechanisms of action through the microbiome must receive regulatory approval in the E.U. and Canada. Regulatory status of such products was undergoing review in the U.S. at the time this report was drafted, but under the status quo, products may be marketed without regulatory review or approval through the Generally Recognized as Safe approach. Crediting methodologies should require sufficient peer-reviewed proof of efficacy and safety of newly developed feed additives, beyond what is required by regulatory approval of these products because regulatory treatment varies between jurisdictions.

FOR MANURE METHODOLOGIES

Strengthen program requirements aimed at protecting local communities, going beyond regulatory requirements where needed to better protect local communities from pollution caused by manure.

Methodologies rely heavily on the enforcement of local regulations such as CAFO permits, which are not always sufficient to address pollution concerns. Therefore, crediting programs should evaluate their environmental and social safeguarding standards to consider whether they sufficiently address these issues for manure-related projects. Ideally, methodologies should require use of treatment technologies to reduce local pollutants, especially ammonia, for digester projects to qualify for GHG crediting. Crediting programs should evaluate how well state regulators consider cumulative public health and environmental impacts when issuing permits for AFOs, CAFO and digesters. This type of detail about the project should be known to credit rating agencies so that buyers know the full value of the efforts associated with the resulting climate mitigation outcomes.

Require consideration of N_2O in baseline and project emissions. Seven of the reviewed methodologies (see Table 6) do not require project proponents to include the calculation of N2O in baseline or project emissions.

The digestate from anaerobic digesters when stored in an open lagoon, commonly known as a secondary lagoon, could result in emissions of N_2O under certain handling situations which might add oxygen to the liquid, however, data is very limited and more work is needed to better understand the potential for N_2O emissions from digestate. Improperly managed compost can create and emit N_2O. This is a serious concern as N_2O is a powerful GHG with approximately 250 times the GWP of CO_2. Including N_2O in net GHG calculations is important to understanding the full climate benefit of manure methane reduction projects.

SCIENTIFIC COMMUNITY

The following recommendations outline actions that the scientific community can take to help support improving the integrity of carbon credits generated from methodologies targeting livestock GHG emissions.

FOR BOTH ENTERIC AND MANURE METHODOLOGIES

Undertake research to provide default values with lower uncertainty and farm system specificity.

Although they might facilitate the monitoring procedure, default values tend to have an inherently higher uncertainty compared to parameters that are monitored. There is a need for research to both improve/update the default values that are prescribed and identify/improve/increase the availability of methodologies to measure emissions. Improved default values should provide a level of granularity that reflects the diversity of conditions and operating practices found at the national or regional level. Where IPCC default values are used, best practice should always be to use Tier 2 (regional) values as a minimum and to use discounting of emissions reductions to correct for the uncertainty inherent in Tier 1 (global default values) where the use of Tier 1 factors cannot be avoided. If default values for emissions factors are not conservative (I.e., Tier 1 global EFs), discount to correct for over-estimation of emissions reductions should be required (e.g., only approve 90% of estimated reductions).

FOR ENTERIC METHODOLOGIES

Support further research on enteric methane inhibitors to demonstrate their efficacy and safety, particularly under different conditions of use.

Standardized, robust and science-based quantification methodologies for measuring enteric methane emissions from cattle are essential for greater precision and accuracy in both baseline emissions from the livestock sector and evaluation of efficacy of mitigation strategies, including feed additives. This is also the case for peer-reviewed research, and it is therefore important to ensure that the source and quality of the research is both relevant and adequate before applying these findings to applications on the ground. Research outputs need to be transparent, easily available and accessible to the target audiences, such as carbon market registries and standards bodies.

Collaborate to develop standardized efficacy testing guidelines for quantification of emissions reductions from feed additives for enteric methane reductions.

Specifically, assessments should consider the net impact of products on GHGs, digestion, nitrogen and phosphorus excretion, and impacts on production efficiency. Any such validation of methodologies requires repeated measurements of gas emissions on the same animal(s) using validated methane measurement techniques within a diurnal cycle and across the lactation cycle under controlled experimental conditions. Correlation coefficients and confidence intervals need to be provided for any such comparison and openly reported in the public domain. Because any potential method may have high within-day and within-animal variance relative to a pre-established standard, any such validation of methods requires a firm understanding of the experimental parameters including the number of animals measured, breed, diet and performance indicators (e.g., level of intake, milk production, body weight). It is also paramount that we validate emissions based on daily methane production, on a 24-hour interval, considering that methane emissions change temporally, and the frequency of measurement varies by method. The frequency and type of calibration and gas recovery tests performed also need to be clearly documented and available for public consideration.

FOR MANURE EMISSIONS

Advance research on how to lower ammonia and N_2O emissions along with methane, from manure and how to scale enabling technologies.

Any manure management system leads to emissions and losses of chemicals like hydrogen sulfide, ammonia, nitrate, methane and N2O. Many of these compounds can be beneficial when contained, but cause harm to human health, the local environment and the climate when released. While manure digesters capture methane and reduce odors, there is little evidence that they reduce the emissions or losses of other gases largely related to the management of digestate. Residual methane losses from the digestate can also be high. For example, recent research indicates that trapping ammonia elevates concentrations to levels up to 3.5 times higher nitrogen content relative to an open lagoon where that ammonia is lost to the atmosphere.[51] However, those avoided ammonia emissions within the digester are lost to the environment if the high ammonia concentration digestate is stored in an open lagoon or tank. The avoided ammonia emissions occurring within the digester present an opportunity to capture a much greater portion of the ammonia in the manure for productive use. More research is needed into opportunities to capture greater amounts of the resources within manure streams as feasible technologies to address local environmental and health impacts from manure management systems.

ACCREDITING AND GOVERNANCE BODIES

It is important that there are strong systems for crediting programs to review and update methodologies with best available research.

Accrediting and governance bodies can play an influential role in creating these systems. Standards bodies (such as the ICVCM, VCMI, CCQI, GHGP and others) influence the governance processes and methodologies that are put in place by carbon registries. For example, it is likely for some of the methodologies that did not receive the recently released CCP label crediting programs will make updates to bring methodologies in line with this new standard. Therefore, ensuring that standards set by these organizations are in line with best available science for livestock emissions MMRV can be an effective pathway to drive adoption of the recommendations outline above.

- Ensure processes are in place to enable updating standards to reflect best available science. Future updates to these standards should ensure that methodologies are reviewed against livestock-specific criteria that consider issues such as:
  - The importance of default values that provide a level of granularity reflecting the diversity of livestock conditions and operating practices found at national or regional levels such as feed quality, typical diets, animal life stage, breed, average climatic conditions and animal stress
  - Current scientific gaps and evolving research for enteric methane inhibiting feed additive safety and efficacy
  - Current scientific gaps and evolving research regarding emissions of other gases in manure management beyond methane
  - Lack of sufficient environmental and community safeguards for manure projects within methodologies

Updating future rounds of standards and industry guidance with the best available science regarding quantification, product eligibility, and social and environmental safeguards is paramount to ensuring continuous improvement at the program level and to continuing to build trust in the voluntary carbon market as a whole.

Appendix: Summary of Assessment Against Specified Criteria

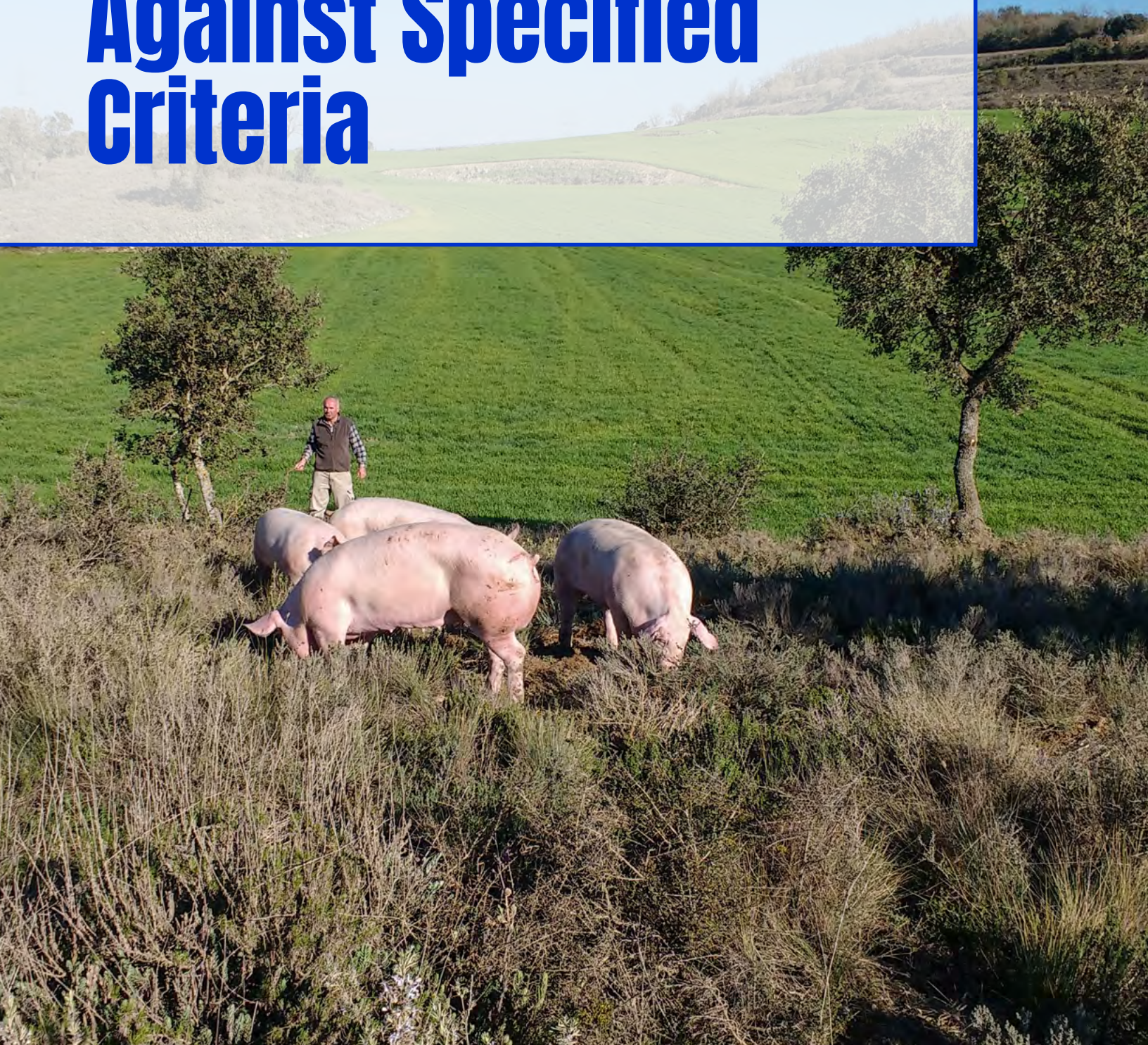


TABLE 11: ADDITIONALITY CRITERIA FOR MANURE MANAGEMENT-RELATED METHODOLOGIES

Methodology	Is proof of additionality required and type of analysis	Basis for demonstration of additionality	Demonstration of prior consideration
Gold Standard: GHG emissions reductions from manure management systems and municipal solid waste	**Investment analysis** and/or **barrier analysis** can be used. Projects seeking to use carbon credits to attract finance shall demonstrate **financial additionality**	Project level	Not required
Gold Standard: Animal manure management and biogas use for thermal energy generation	**Investment analysis** and/or **barrier analysis** can be used. Projects seeking to use carbon credits to attract finance shall demonstrate **financial additionality**	Project level	Not required
Climate Action Reserve: U.S. livestock project protocol V4.0	**Investment analysis** and/or **barrier analysis** can be used	Project level	Not required
California's Low Carbon Fuel Program: Low carbon fuel standard regulation	**Legal additionality** is the only requirement	Project level	Not required
California's ETS: Capturing and destroying methane from manure management systems	**Legal additionality** and **performance standard evaluation** related to design of lagoons and common practice	Project level	Not required
U.S. EPA: Renewable fuel standard program	Not required	Not required	Not required
U.S. Regional Greenhouse Gas Initiative: Model offset consistency applications and model monitoring and verification reports	**Legal additionality** is the only requirement	Project level	Not required
Alberta: Quantification protocol for biogas production and combustion	**Investment analysis** or **barrier analysis** used to demonstrate additionality. Where relevant **penetration rate** on its own may be sufficient to demonstrate additionality	Methodology level	Not required

Methodology	Is proof of additionality required and type of analysis	Basis for demonstration of additionality	Demonstration of prior consideration
U.N. Clean Development Mechanism, AMS-III.R.: Methane recovery in agricultural activities at household/small farm level	**Investment analysis** and/or **barrier analysis** can be used. Small-scale digesters on a positive list of technologies	Project level; special rules apply for small-scale biogas digesters	Required
U.N. Clean Development Mechanism, AM0073: GHG emissions reductions through multi-site manure collection and treatment in a central plan	**Investment analysis** and/or **barrier analysis** can be used	Project level	Required
U.N. Clean Development Mechanism, ACM0010: GHG emissions reductions from manure management systems	**Investment analysis** and/or **barrier analysis** can be used	Project level	Required
U.N. Clean Development Mechanism, AMS-III.D.: Methane recovery in animal manure management systems (Small Scale)	**Legal additionality** is the only requirement	Project level.	Required
U.N. Clean Development Mechanism, AMS-III.Y: Methane avoidance through separation of solids from manure treatment system	**Investment analysis** and/or **barrier analysis** can be used	Project Level	Required
Australia: Animal effluent management	**Legal additionality** is the only requirement. The project must not start before registration and is unlikely to be carried out under another government program	Project level	Not required

TABLE 12: ADDITIONALITY CRITERIA FOR PROJECTS RELATED TO ENTERIC FERMENTATION

Methodology	Required proof of additionality and type of analysis	Level of demonstration required	Demonstration of prior consideration required?
Gold Standard: Reducing methane emissions from enteric fermentation in dairy cows through application of feed supplements	Projects seeking to use carbon credits to attract finance shall demonstrate **financial additionality. Investment analysis** and/or **barrier analysis** can be used	Demonstrated at the **project level**	No
Gold Standard: Methodology for quantification of GHG emissions reductions from improved management in smallholder dairy production systems using a standardized baseline	Projects seeking to use carbon credits to attract finance shall demonstrate **financial additionality. Investment analysis** and/or **barrier analysis** can be used	Demonstrated at the **project level**	Yes
Gold Standard: Methane emissions reduction from enteric fermentation in beef cattle through application of feed supplements	**Legal additionality** is the key requirement. Projects also need to demonstrate **financial additionality. Investment analysis** and/or **barrier analysis** can be used	Demonstrated at the **project level**	No
Verified Carbon Standard: Methodology for the reduction of enteric methane emissions from ruminants through the use of feed ingredients	**Investment analysis** and/or **barrier analysis** can be used	Demonstrated either at **project level** or for **project types** using standardized approaches	No
Canada's GHG offset credit system: Reducing enteric methane emissions from beef cattle (Draft)	**Legal additionality** is the key requirement	Demonstrated at the **project level**	No
Alberta Emissions Offset System: Quantification protocol for selection for low residual feed intake in beef cattle	**Investment analysis** or **barrier analysis** used to demonstrate additionality. Where relevant, how widely the technology or solution has been adopted (i.e., **penetration rate)** may be sufficient to demonstrate additionality	Demonstrated at **protocol level**	No

Methodology	Required proof of additionality and type of analysis	Level of demonstration required	Demonstration of prior consideration required?
Alberta Emissions Offset System: Quantification protocol for reducing greenhouse gas emissions from fed cattle	**Investment analysis** or **barrier analysis** used to demonstrate additionality. Where relevant, **penetration rate** on its own may be sufficient to demonstrate additionality	Demonstrated at **protocol level**	No
U.N. Clean Development Mechanism, AMS-III. BK.: Strategic feed supplementation in smallholder dairy sector to increase productivity	**Investment analysis** and/or **barrier analysis** can be used	Demonstrated at the **project level**	Yes
Australian Emissions Reduction Fund: Reducing emissions by feeding dietary additives to milking cows	**Legal additionality** is the key requirement. The project must not start before registration and is unlikely to be carried out under another government program	Demonstrated at the **project level**	No
Australian Emissions Reduction Fund: Reducing emissions by feeding nitrates to beef cattle	**Legal additionality** is the key requirement. The project must not start before registration and is unlikely to be carried out under another government program	Demonstrated at the **project level**	No
Australian Emissions Reduction Fund: Beef cattle herd management	**Legal additionality** is the key requirement. The project must not start before registration and is unlikely to be carried out under another government program	Demonstrated at the **project level**	No

TABLE 13: APPROACHES TO DETERMINING SYSTEMIC LEAKAGE EMISSIONS THROUGHOUT THE ENTERIC METHANE REDUCTION METHODOLOGIES

Methodology	Systemic Leakage
Gold Standard: Reducing methane emissions from enteric fermentation in dairy cows through application of feed supplements	States that there is little to no risk
Gold Standard: Methodology for quantification of GHG emissions reductions from improved management in smallholder dairy production systems using a standardized baseline	Requires projects to assess and account for the risk of land use change induced by demand for feed
Gold Standard: Methane Emissions Reduction from Enteric Fermentation in Beef Cattle Through Application of Feed Supplements	Considered to be zero
Verified Carbon Standard: Methodology for the reduction of enteric methane emissions from ruminants through the use of feed ingredients	Considered to be zero
Canada's GHG offset credit system: Reducing enteric methane emissions from beef cattle (Draft)	Leakage is addressed by quantifying GHG emissions in the baseline scenario relative to the unit mass of beef produced in the project scenario to ensure functional equivalency between the baseline and project scenarios in order to account for **systemic leakage**
Alberta Carbon Offset Program: Quantification protocol for selection for low residual feed intake in beef cattle	Not mentioned
Alberta Carbon Offset Program: Quantification protocol for reducing greenhouse gas emissions from fed cattle	Not mentioned
U.N. Clean Development Mechanism, AMS-III.BK.: Strategic feed supplementation in smallholder dairy sector to increase productivity	If urea is used in the supplementation, emissions from production of urea shall be considered
Australian Emissions Reduction Fund: Reducing emissions by feeding dietary additives to milking cows	Not mentioned
Australian Emissions Reduction Fund: Reducing emissions by feeding nitrates to beef cattle	Not mentioned
Australian Emissions Reduction Fund: Beef cattle herd management	Not mentioned

TABLE 14: APPROACHES TO DETERMINING PROJECT AND SYSTEMIC LEAKAGE EMISSIONS THROUGHOUT THE MANURE-RELATED METHODOLOGIES

Methodology	Leakage
Gold Standard: GHG emissions reductions from manure management systems and municipal solid waste	Covers emissions from land application of treated manure occurring outside the project boundary, as well as the emissions from an anaerobic digester
Gold Standard: Animal manure management and biogas use for thermal energy generation	Consider if digestate is being stored under anaerobic conditions which lead to methane emissions due to further anaerobic digestion of the residual biodegradable organic matter. If applicable, requires proper soil application of the digestate to avoid methane emissions; verified on a sampling basis following the "Standard for sampling and surveys for CDM project activities and programme of activities"
Climate Action Reserve: U.S. livestock project protocol V4.0	Not addressed
California's Low Carbon Fuel Program: Low carbon fuel standard regulation	Not addressed
California's ETS: Capturing and destroying methane from manure management systems	A significant number of emissions allowances are freely allocated for transition assistance and to reduce project leakage
U.S. EPA: Renewable fuel standard program	Not addressed
U.S. Regional Greenhouse Gas Initiative: Model offset consistency applications and model monitoring and verification reports	Not addressed
Australia: Animal effluent management	Not addressed
Alberta: Quantification protocol for biogas production and combustion	Linked to the concept of additionality of activities: an activity must always result in a net emissions reduction or removal. Project developers must provide a written explanation of how the project ensures there is no emissions leakage

Methodology	Leakage
U.N. Clean Development Mechanism, AMS-III.R.: Methane recovery in agricultural activities at household/small farm level	Calculates emissions related to use of biomass in small-scale project activities
U.N. Clean Development Mechanism, AM0073: GHG emissions reductions through multi-site manure collection and treatment in a central plan	Calculates emissions from land application of treated residues, outside the project boundary
U.N. Clean Development Mechanism, ACM0010: GHG emissions reductions from manure management systems	Calculates emissions from land application of treated residues, outside the project boundary
U.N. Clean Development Mechanism, AMS-III.D.: Methane recovery in animal manure management systems (Small Scale)	Calculates emissions from biogas in the manure management systems: production, collection, transport, flaring/combustion or gainful use. Systemic leakage not addressed
U.N. Clean Development Mechanism, AMS-III.Y: Methane avoidance through separation of solids from manure treatment system	Calculates the emissions from any solid separation technology, equipment transferred from another activity and from any flocculants that were manufactured and not a waste product

ENDNOTES

1 Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A. & Tempio, G. 2013. "Tackling climate change through livestock — A global assessment of emissions and mitigation opportunities." Food and Agriculture Organization of the United Nations (FAO), Link.

2 CO_2 equivalents used in this report are based on 100-year GWPs (or GWP-100) from the Intergovernmental Panel on Climate Change's Fourth Assessment report, unless indicated otherwise. GWP is a measure of the relative influence of a unit (e.g., 1 kg) of a GHG on global temperature within a given time horizon, which can be a 100-year or 20-year period (EPA 2020). Expressing non-CO_2 GHGs as CO_2e involves weighing gases by their GWP, in comparison to that of CO_2. The GWP for methane over a 20-year time period is about three times greater than when considered over a 100-year time period.

3 United Nations Environment Programme/Climate and Clean Air Coalition (2022). "Global Methane Assessment: 2030 Baseline Report." https://www.globalmethanepledge.org/

4 World Bank, "State and Trends of Carbon Pricing, 2024", http://hdl.handle.net/10986/41544

5 Enteric fermentation is a natural part of the digestive process in ruminant animals such as cattle, sheep, goats and buffalo. Microbes in the digestive tract, or rumen, decompose and ferment food, producing methane as a by-product.

6 While the UN CDM registry is no longer accepting new projects, UN CDM methodologies can be used to register projects in the voluntary carbon market, such as under the Verra VCS and Gold Standard registries, which is the basis for the inclusion of these methodologies in our review.

7 All 10 core carbon principles can be found at https://icvcm.org/core-carbon-principles/

8 Integrity Council for Voluntary Carbon Market. "Core Carbon Principles, assessment framework, and assessment procedure. Version 1.1" 2024. https://icvcm.org/assessment-framework/

9 1) Jose A. Del Real. "They Grow the Nation's Food, but They Can't Drink the Water" New York Times. 2019. Link; 2) V. Blanes-Vidal et al., "Characterization of Odor Released During Handling of Swine Slurry: Part I. Relationship between Odorants and Perceived Odor Concentrations" Atmospheric Env't 18. 2009. https://doi.org/10.1016/j.atmosenv.2008.10.016 3) CARB. "Assembly Bill 32 Environmental Justice Advisory Committee Meeting Minutes" 2023. Link 4) Domingo, Nina G. G., et al., "Air quality–related health damages of food." Proceedings of the National Academy of Sciences Vol. 118, 2021. https://doi.org/10.1073/pnas.2013637118

10 EDF. "Methane: A crucial opportunity in the climate fight." Accessed 2024. https://www.edf.org/climate/methane-crucial-opportunity-climate-fight

11 CO_2 equivalents used in this report are based on 100-year GWPs (or GWP-100) from the Intergovernmental Panel on Climate Change's Fourth Assessment report, unless indicated otherwise. GWP is a measure of the relative influence of a unit (e.g., 1 kg) of a GHG on global temperature within a given time horizon, which can be a 100-year or 20-year period (EPA 2020). Expressing non-CO_2 GHGs as CO_2e involves weighting gases by their GWP, in comparison to that of CO_2.

12 EDF. "Tackling enteric methane: Designing effective methane solutions informed by U.S. dairy and beef producers' perspectives." 2022. https://business.edf.org/wp-content/blogs.dir/90/files/EDF026_Farm-First_V4_8-2.pdf

13 Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A. & Tempio, G. 2013. "Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities." Food and Agriculture Organization of the United Nations (FAO), Link. page xii

14 Enteric fermentation is a natural part of the digestive process in ruminant animals such as cattle, sheep, goats and buffalo. Microbes in the digestive tract, or rumen, decompose and ferment food, producing methane as a by-product.

15 Blaufelder, Christopher et al., "A Blueprint for Scaling Voluntary Carbon Markets to Meet the Climate Challenge." McKinsey and Company. 2021. https://www.mckinsey.com/capabilities/sustainability/our-insights/a-blueprint-for-scaling-voluntary-carbon-markets-to-meet-the-climate-challenge

16 The Regional Greenhouse Gas Initiative (RGGI) covers the states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont and Virginia to cap and reduce CO_2 emissions from the power sector.

17 Scope 3 emissions are emissions that an entity (such as a corporation) indirectly affects in its value chain, also referred to as value chain emissions. Source: EPA "Scope 3 Inventory Guidance." Accessed 2024. https://www.epa.gov/climateleadership/scope-3-inventory-guidance

18 While the UN CDM registry is no longer accepting new projects, UN CDM methodologies can be used to register projects in the voluntary carbon market, such as under the Verra VCS and Gold Standard registries, which is the basis for the inclusion of these methodologies in our review.

19 EDF, "AT A GLANCE: Enteric emissions reduction opportunities." 2022. https://business.edf.org/wp-content/blogs.dir/90/files/Biz-Animal-Ag-060622-HighRes.pdf

20 EPA. "Integrated Risk Information System (IRIS) Chemical Assessment Summary Bromoform; CASRN 75-25-2" https://cfpub.epa.gov/ncea/iris/iris_documents/documents/subst/0214_summary.pdf

21 Verra. "VM0041 Methodology for the Reduction of Enteric Methane Emissions from Ruminants through the Use of Feed Ingredients, v2.0" 2021. https://verra.org/methodologies/revision-to-vm0041-methodology-for-the-reduction-of-enteric-methane-emissions-from-ruminants-through-the-use-of-100-natural-feed-supplement-v1/

22 Gold Standard. "Gold Standard Agriculture Smallholder Dairy Methodology" 2017. https://globalgoals.goldstandard.org/405-luf-agr-agriculture-smallholder-dairy-methodology/

23 UNDCC CDM. "AMS-III.BK.: Strategic feed supplementation in smallholder dairy sector to increase productivity — Version 2.0" 2021." https://cdm.unfccc.int/methodologies/DB/V2AIKU3OM6H40CHX1QKYDLPE1CXTO5

24 Environment and Climate Change Canada. "Reducing Enteric Methane Emissions from Beef Cattle. Federal Offset Protocol Public Consultation Draft." 2023. Canada's Greenhouse Gas Offset Credit System. https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/output-based-pricing-system/federal-greenhouse-gas-offset-system/protocols/draft-reducing-enteric-methane-emissions-beef-cattle.html

25 Integrity Council for Voluntary Carbon Market. "Core Carbon Principles, assessment framework, and assessment procedure. Version 1.1" 2024. https://icvcm.org/assessment-framework/

26 EDF, WWF and Oeko Institut. "What makes a high-quality carbon credit? Phase 1 of the "Carbon Credit Guidance for Buyers" project: Definition of criteria for assessing the quality of carbon credits." 2020. https://www.edf.org/sites/default/files/documents/what_makes_a_high_quality_carbon_credit.pdf

27 Integrity Council for Voluntary Carbon Market. "Core Carbon Principles, assessment framework, and assessment procedure. Version 1.1" 2024. https://icvcm.org/assessment-framework/

28 For example, see SustainCert "Must my Gold Standard project demonstrate ongoing financial need?" https://sustaincert.zohodesk.com/portal/en/kb/articles/must-my-gold-standard-project-demonstrate-ongoing-financial-need

29 UNCDM. "Tool 32 Methodological Tool, Positive List of Technologies." 2022. https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-32-v4.0.pdf

30 Integrity Council for Voluntary Carbon Market. "Core Carbon Principles, assessment framework, and assessment procedure. Version 1.1" 2024. https://icvcm.org/assessment-framework/

31 A.N. Hristov, A. Melgar, "Short communication: Relationship of dry matter intake with enteric methane emission measured with the GreenFeed system in dairy cows receiving a diet without or with 3-nitrooxypropanol" Animal. 2020. https://doi.org/10.1017/S1751731120001731.

32 Ibid.

33 https://www.fao.org/3/i3461e/i3461e.pdf

34 FAO and GDP. 2018. Climate change and the global dairy cattle sector – The role of the dairy sector in a low-carbon future. Rome. 36 pp. Licence: CC BY-NC-SA- 3.0 IGO. Link.

35 Global Agenda for Sustainable Livestock. "Climate change and the global dairy cattle sector — The role of the dairy sector in a low-carbon future." Food and Agriculture Organization of the UN and Global Dairy Platform, 2018. http://www.fao.org/3/CA2929EN/ca2929en.pdf

36 Vergot, Tine L.I. et al., "Monitoring methane and nitrous oxide emissions from digestate storage following manure mono-digestion." Biosystems Engineering. 2020. https://doi.org/10.1016/j.biosystemseng.2020.05.011

37 IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds).Volume 4, Chapter 10. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf

38 IPCC 2019, 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Calvo Buendia, E., Tanabe, K., Kranjc, A., Baasansuren, J., Fukuda, M., Ngarize, S., Osako, A., Pyrozhenko, Y., Shermanau, P. and Federici, S. (eds). Published: IPCC, Switzerland. https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch10_Livestock.pdf

39 Charlotte Scheutz, Anders M. Fredenslund, "Total methane emission rates and losses from 23 biogas plants," Waste Management, Volume 97, 2019, https://doi.org/10.1016/j.wasman.2019.07.029

40 Table 10.12, IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds)..Volume 4, Chapter 10. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf

41 Ginny Sherwin, Rebecca Nelson, Mike Kerby, John Remnant, "Clinical examination of cattle. Part 2: calves, technology and ancillary testing," In Practice, 2022. https://doi.org/10.1002/inpr.237

42 Wilfred O. Odadi, "Using heart girth to estimate live weight of heifers (Bos indicus) in pastoral rangelands of northern Kenya," Livestock Research for Rural Development. 2018. http://www.lrrd.org/lrrd30/1/wood30016.html

43 National Research Council "The Scientific Basis for Estimating Emissions from Animal Feeding Operations," National Academy Press. 2002, https://www.epa.gov/sites/default/files/2020-10/documents/interimanimalfeed_0.pdf

44 Alberta: Quantification protocol for selection for low residual feed intake in beef cattle and Quantification Protocol for Reducing Greenhouse Gas Emissions from Fed Cattle; Australia: Reducing emissions by feeding dietary additives to milking cows, Reducing emissions by feeding nitrates to beef cattle, Beef cattle herd management; Gold Standard: Methodology for Quantification of GHG Emission Reductions from Improved Management in Smallholder Dairy Production Systems using a Standardized Baseline

45 CARB. "Assembly Bill 32 Environmental Justice Advisory Committee Meeting Minutes" 2023. Link

46 EDF, WWF and Oeko Institut. "What makes a high-quality carbon credit? Phase 1 of the "Carbon Credit Guidance for Buyers" project: Definition of criteria for assessing the quality of carbon credits." 2020. https://www.edf.org/sites/default/files/documents/what_makes_a_high_quality_carbon_credit.pdf

47 United Nations. “The 17 Goals.” Accessed 2024. https://sdgs.un.org/goals

48 FAO. “Indigenous Peoples: Free Prior and Informed Consent.” Accessed 2024. https://www.fao.org/indigenous-peoples/our-pillars/fpic/en/

49 1) Jose A. Del Real. “They Grow the Nation’s Food, but They Can’t Drink the Water” New York Times. 2019. Link; 2) V. Blanes-Vidal et al., “Characterization of Odor Released During Handling of Swine Slurry: Part I. Relationship between Odorants and Perceived Odor Concentrations” Atmospheric Env’t 18. 2009. https://doi.org/10.1016/j.atmosenv.2008.10.016 3) CARB. “Assembly Bill 32 Environmental Justice Advisory Committee Meeting Minutes” 2023. Link 4) Domingo, Nina G. G., et al. “Air quality–related health damages of food.” Proceedings of the National Academy of Sciences Vol. 118, 2021. https://doi.org/10.1073/pnas.2013637118

50 Joe Rudek and Stefan Schwietze. “Not all Biogas is Created Equal”, EDF Blog. 2019. https://blogs.edf.org/energyexchange/2019/04/15/not-all-biogas-is-created-equal//

51 S.G. Lupis, “Best Management Practices for Reducing Ammonia Emissions: Lagoon Covers.” Colorado State University Extension. 2012. https://extension.colostate.edu/topic-areas/agriculture/best-management-practices-for-reducing-ammonia-emissions-lagoon-covers-1-631b/



envdefensefund

envdefensefund

environmental_defense_fund

environmental-defense

envdefensefund

edf.org

257 Park Avenue South, New York, New York 10010
© 2024 Environmental Defense Fund