Policy Maker's Handbook for Measurement, Reporting, and Verification in the Biogas Sector

January 2022

Prepared by the
United States Environmental Protection Agency
on behalf of the
Global Methane Initiative

EPA Document Number: EPA 430-B-21-002

Policy Maker’s Handbook for Measurement, Reporting, and Verification in the Biogas Sector

January 2022

Prepared by the

United States Environmental Protection Agency

on behalf of the

Global Methane Initiative

Contents

List of Acronyms and Abbreviations

Biogas sector	agriculture (agro-residue and manure management), municipal solid waste, and municipal wastewater sectors, collectively
BOD	biological oxygen demand
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
COD	chemical oxygen demand
EPA	United States Environmental Protection Agency
FOD	first order decay
GHG	greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
IPCC	Intergovernmental Panel on Climate Change
MRV	measurement, reporting, and verification
NDC	nationally determined contribution
NGO	nongovernmental organization
QA/QC	quality assurance/quality control
SDG	Sustainable Development Goal
SLCP	short-lived climate pollutant
SWEET	Solid Waste Emissions Estimation Tool
UNFCCC	United Nations Framework Convention on Climate Change
WRI	World Resources Institute

Acknowledgements

This handbook was developed by the United States Environmental Protection Agency (EPA) on behalf of the Global Methane Initiative. It was developed with support from Abt Associates, Ruby Canyon Environmental, Nimmi Damodaran, SCS Engineers, The Energy and Resources Institute, THINKcities, and Leandro Buendia.

EPA would like to thank the following individuals for their assistance in reviewing draft versions of the handbook:

- Anthy Alexiades, Matthew Harrison, and Ryan Schauland, California Air Resources Board
- Claire Cvitanovich and Kathryn Zook, United States Department of Agriculture
- Gerardo Canales Gonzalez, ImplementaSur
- Jorge Hilbert, Argentina National Institute of Agricultural Technology
- Laurel Pegorsh, Oxfam America
- Manas Puri and Luis Rincón, United Nations Food and Agriculture Organization
- Matthew Hamilton, Environment and Climate Change Canada
- Neelam Singh, World Resources Institute

Disclaimer

EPA prepared this handbook for educational purposes only. EPA does not endorse or support any specific technology, service, or project mentioned in the handbook.

Executive Summary

The agriculture,[1] municipal solid waste, and municipal wastewater sectors - collectively referred to as the biogas sector in this handbook - account for approximately one-fifth of global anthropogenic methane emissions (GMI, 2020). Projects that capture and use this methane, such as anaerobic digestion and landfill gas energy projects, can deliver a range of benefits, including climate change mitigation, energy generation, and public health protection.

Many governments struggle to account for emissions reductions from biogas projects. This has implications for governments' ability to fully reap the benefits of these projects at scale (e.g., by impeding efforts to generate revenues through carbon markets, which require accurate emissions reduction accounting). One of the barriers to effective accounting of biogas project emissions and reductions is decision-makers' limited access to clear guiding principles for emissions measurement, reporting, and verification (MRV).

This handbook addresses that need. It serves as a high-level resource, intended primarily for national governments, on best practices for project-level MRV in the biogas sector (e.g., using established methodologies and techniques, as well as robust tools and resources) to support national-level objectives. These objectives include developing robust greenhouse gas (GHG) emissions inventories; enhancing targets, policies, and actions in nationally determined contributions (NDCs) for emissions reductions; demonstrating progress toward sustainable development goals; and increasing access to external funding sources to promote economic growth.

Overview of MRV

There are three components of an effective MRV framework:

- **Measurement** involves the tracking and documentation of data and information on GHG emissions or emissions reductions from the biogas sector. The measurement of emissions, emissions reductions, and other information is often completed by the entity that owns or has developed the project, or by an independent consultant with specific expertise in GHG accounting and documentation.
- **Reporting** entails the dissemination of measured GHG emissions and emissions reduction data and information using standardized methods and formats. Uniform data platforms and systematic data aggregation help ensure accurate and transparent GHG accounting.
- **Verification** is an independent assessment of reported GHG emissions and emissions reductions. It is typically undertaken by an independent, third-party verification body to ensure impartial assessment.

Effective MRV is an ongoing process that is repeated throughout the life of a project, often annually.

Using Biogas Project MRV Data to Develop Robust National GHG Inventories

The *2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories* provide three tiers of methods for estimating emissions from a particular source:

- Tier 1 methods are based on generic models and default values. These methods result in higher uncertainties.

[1] Throughout the handbook, the agriculture sector refers to agro-residue and manure management activities

- Tier 2 methods build on Tier 1 methods, but often include country-specific data and have lower uncertainties.
- Tier 3 methods use country- and facility-specific data and tailored models to produce estimates that typically have the lowest uncertainties.

Many governments use Tier 1 methods for emissions categories in the biogas sector, often due to limited availability of country-specific data. However, using these methods results in high levels of uncertainty. As described in this handbook, governments can use data acquired through project-level MRV to advance beyond Tier 1 methods by:

- **Refining Recovery Estimates:** Governments can use data on methane recovery from biogas projects to develop nation-specific recovery rates and improve inventories, rather than using generic default values.
- **Improving Activity Data:** Governments can leverage biogas project MRV of emissions to develop better-informed estimates of activities that contribute emissions and practices that avoid them. Relying on IPCC default values for activity data contributes a great deal of uncertainty (the guidelines provide suggested uncertainty bounds).
- **Developing Country-Specific Emissions Factors:** Governments can use project-level MRV data to develop country-specific emissions factors for biogas sector sources.

Using Biogas Project MRV Data to Enhance Mitigation Targets in NDCs

Actions in the biogas sector can play a critical role in meeting global GHG mitigation targets. The availability of accurate and complete data is critical to the development of robust climate mitigation targets and strategies. In the biogas sector, project-level MRV can be a valuable source of data for establishing national emissions reductions baselines and projections.

As governments develop their NDCs, they can consider advancing efforts to mitigate biogas sector methane emissions by:

- Identifying the largest sources of anthropogenic methane emissions in the biogas sector (e.g., landfills, wastewater treatment facilities, livestock operations).
- Establishing emissions reductions goals to reduce methane emissions from the biogas sector in their NDCs.
- Identifying specific strategies to mitigate anthropogenic methane by sector and source category (e.g., requiring methane recovery from all new landfills). The Global Methane Initiative is a source of information on best practices for methane mitigation across the biogas sectors.
- Establishing protocols for measuring methane emissions and emissions reductions for incorporation into national communications.
- Developing a national database of emissions reductions to more easily track and link project-level data to NDC commitments.
- Indicating in their NDCs where the country is lacking the resources or capacity required to collect data to make project-level MRV viable.

Several countries, including Rwanda, Dominica, and Uruguay, have included methane emissions mitigation targets in their NDCs (discussed further in Section 5). Project-level MRV can help demonstrate countries' progress toward achieving these quantitative targets.

1. Introduction

The agriculture,[2] municipal solid waste, and municipal wastewater sectors - collectively referred to as the biogas sector in this handbook - account for approximately one-fifth of global anthropogenic methane emissions (GMI, 2020). Cost-effective strategies for capturing and using this methane, including those identified in Exhibit 1, can deliver a range of benefits, such as climate change mitigation, energy generation, and public health protection (see Exhibit 2).

Despite the substantial benefits of biogas projects, many governments struggle to account for the emissions reductions they generate. One of the barriers to effective accounting of biogas project emissions and reductions is decision-makers' limited access to clear guiding principles for emissions measurement, reporting, and verification (MRV). Project-level MRV is the process of **measuring** GHG emissions and emissions reductions from individual projects or activities; **reporting** emissions and reductions to government agencies, shareholders, partners, and other invested parties; and **verifying** emissions and reductions through an independent audit.

This handbook provides information on guiding principles for conducting emissions MRV for biogas sector projects. It serves as a high-level resource, primarily for national governments, on how best practices for project-level MRV in the biogas sector can be applied to support national-level objectives, including developing national GHG inventories and establishing national emissions mitigation goals.

Exhibit 2. Why Focus on Methane?

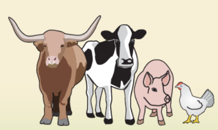
The biogas sector produces emissions of several greenhouse gases (GHGs) including methane, carbon dioxide (CO_2), and nitrous oxide. Methane, a hydrocarbon, is the primary component of natural gas and a very potent and important GHG. Although methane is emitted into the atmosphere in smaller quantities than CO_2, its global warming potential is 28–34 times that of CO_2, resulting in methane's stronger influence on warming during its 12-year atmospheric lifetime. Unlike other GHGs, methane can be converted to usable energy. Methane is also an important precursor to tropospheric ozone, and reducing methane contributes to reductions in ozone-related health effects. For more information, visit the Global Methane Initiative's website at www.globalmethane.org.

Exhibit 1. Example Methane Emissions Mitigation Strategies in the Biogas Sector

Municipal Solid Waste

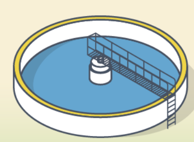
Landfill gas collection, control, and utilization

Anaerobic digestion of organic waste including food and green waste



Agriculture

Anaerobic digestion of livestock manure and crop residues



Municipal Wastewater

Anaerobic digestion of biosolids

[2] Throughout the handbook, the agriculture sector refers to agro-residue and manure management activities.

1.1 Importance of Robust Accounting for Emissions and Emissions Reductions from Biogas Projects

Approaches to quantifying emissions and emissions reductions from biogas projects are often inconsistent, incomplete, and inadequate, making it difficult for governments to account for them. This can impact governments in several important ways:

- **GHG inventories.** It is good practice for countries to use higher-tier methodologies to estimate GHG emissions in their inventories, especially for key categories of emissions (e.g., the largest sources). Using higher-tier methodologies, which are based on better-quality local data, result in lower uncertainties. Often, poor-quality, country-specific data prevents governments from advancing to higher-tier methods (see Section 4 for more information).
- **National emissions reductions targets.** In 2020 and 2021, many countries prepared updated nationally determined contributions (NDCs) under the Paris Agreement within the United Nations Framework Convention on Climate Change (UNFCCC). Limited data on potential and actual emissions reductions from the biogas sector hinder countries' abilities to account for these actions in their NDCs and other national emissions reductions goals (see Section 5 for more information).
- **Sustainable Development Goals (SDGs).** Reducing methane emissions from the biogas sector can contribute to several United Nations' SDGs. Poor accounting of emissions reductions from this sector impairs governments' ability to report on progress toward these and other development goals they have adopted.
- **Carbon markets and climate finance.** Securing financing and funding for emissions mitigation projects requires robust accounting for emissions reductions technologies, operations, and outcomes. Without strong accounting practices, governments and other project stakeholders struggle to obtain the financial resources needed to build and operate projects sustainably.

1.2 Addressing Barriers to Emissions Reductions Accounting

Purpose of this Handbook

The handbook provides information on guiding principles for conducting emissions MRV for biogas sector projects. This information is intended for government decision-makers and the wide range of other stakeholders who play a role in project-level MRV.

The handbook is also meant to serve as a high-level resource for national governments on how best practices for project-level MRV in the biogas sector can be applied to support national-level objectives. In particular, it addresses how national governments can use these best practices to improve their GHG inventories and develop enhanced mitigation goals as part of their NDCs.

This handbook is not meant to be a comprehensive implementation guide for conducting MRV activities. Rather, it draws on technical guidance and tools from a range of protocols developed by other organizations and initiatives, such as the Intergovernmental Panel on Climate Change (IPCC), the United States Environmental Protection Agency's (EPA's) AgSTAR Program, the California Air Resources Board, and others identified in Appendix A. It is meant to support decision-makers in incorporating project-level emissions and emissions reductions from the biogas sector into frameworks for developing GHG inventories, reporting on climate mitigation efforts, and other objectives. For more information on MRV activities in general, see the resources described in Appendix A.

Audience

This handbook was developed for government decision-makers, primarily at the national level. However, the principles of project-level MRV presented in this handbook can be applied at all levels of government. The handbook provides information and resources that can be useful for a wide range of other biogas sector stakeholders, including cities and other sub-national governments, government technical staff, nongovernmental organizations (NGOs), project developers, operators, financial institutions, and other private sector organizations.

Scope

The handbook is focused on MRV principles for the **biogas sector**, including the agriculture, municipal solid waste, and municipal wastewater sectors. The handbook is also focused on **project-level activities** (i.e., practices and technologies), such as anaerobic digesters or landfill gas projects. This handbook intentionally does not address broader-scale MRV-related activities and systems, such as sector-wide Nationally Appropriate Mitigation Action programs or national-level systems for preparing reports to the UNFCCC.

Contents of the Handbook

The remainder of this handbook is organized as follows:

- **Section 2 – Overview of MRV Basics**, provides information on components of MRV, benefits of project-level MRV activities in the biogas sector (especially for national governments), and key stakeholders in project-level MRV activities.
- **Section 3 – Best Practices for Project-Level MRV in the Biogas Sector**, provides details on the practical application of best practices for project-level MRV in the biogas sector.
- **Section 4 – Using Biogas Project MRV Data to Develop Robust National GHG Inventories**, provides examples of how governments can use project-level MRV data to increase the accuracy and comprehensiveness of their GHG emissions inventories.
- **Section 5 – Using Biogas Project MRV Data to Enhance Mitigation Targets in NDCs**, explains how national governments can apply MRV best practices to track and enhance biogas sector methane emissions reductions targets in their NDCs.
- **Section 6 – Summary**, provides a brief summary of key points.

These are followed by a Bibliography and several appendices:

- **Appendix A – Helpful Resources**, provides links to a range of resources, reports, and guidelines; and tools related to MRV, national GHG inventories, and NDCs.
- **Appendix B – Project Type-Specific Emissions Measurement Techniques**, provides detailed information on methodologies for measuring emissions from different types of biogas projects, such as landfill gas and anaerobic digestion projects.
- **Appendix C – Biogas Emissions Quantification Tools and Resources**, provides additional information about calculators and models that can be used to quantify emissions from the biogas sector.
- **Appendix D – Verification Best Practices**, provides additional detail on the steps involved in conducting verification activities for projects in the biogas sector.

2. Overview of MRV Basics

This section provides a general review of the basics of project-level MRV, including essential components of an MRV framework, benefits of project-level MRV for governments, and key stakeholders involved in project-level MRV. The handbook refers to two different types of MRV—MRV of emissions and MRV of mitigation actions (or emissions reductions); the distinction between the two is discussed in Exhibit 3. This handbook primarily discusses MRV of emissions reductions as it focuses on project-level data.

Exhibit 3. MRV of Emissions and Mitigation Actions

MRV can be used in a variety of circumstances, but the nature of the MRV activities differs depending on the context. This handbook discusses two main types of MRV:

- **MRV of Emissions** seeks to understand overall emissions of an entity over time. It is generally performed at a national, organization, or facility level.
- **MRV of Mitigation Actions** (i.e., emission reductions) seeks to understand the change in emissions resulting from a project or policy.

Source: WRI, 2016.

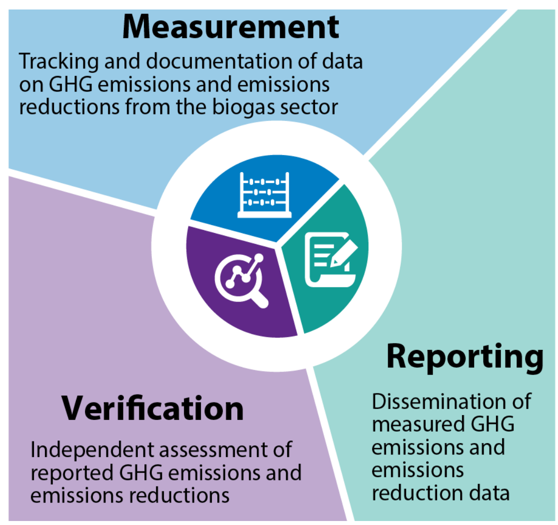
2.1 What Are the Components of an Effective MRV Framework?

As shown in Exhibit 4, the three components of an effective MRV framework include:

- Measurement is the tracking and documentation of data and information on GHG emissions or emissions reductions from the biogas sector. This can involve the direct monitoring of emissions and emissions reductions (e.g., using biogas flow meters), modeling (e.g., using emissions factors and activity data to estimate emissions), or a combination thereof (e.g., subtracting measured emissions reductions from multiple projects from modeled sector-level emissions to estimate net total emissions reductions).

  The measurement of emissions, emissions reductions, and other information is often completed by the entity that owns or has developed the project, or by an independent consultant with specific expertise in GHG accounting and documentation. The requirements of the reporting program (discussed in Section 3) will help determine who will need to measure or monitor emissions or emissions reductions. For example, measuring reductions to sell as offset credits will likely require more third-party input and oversight.

Exhibit 4. MRV Components



- Reporting entails the dissemination of measured GHG emissions and emissions reduction data and information using standardized methods and formats. Uniform data platforms and systematic data aggregation help ensure accurate and transparent GHG accounting. Project operators and other reporting entities might submit their data to various types of organizations or reporting programs, including government agencies, NGOs, financial institutions, and shareholders, among others. Reporting requirements will vary depending on a range of factors. For example, some countries require emissions data reporting for inventories and have their own registry systems for GHG emissions (e.g., Mexico's Cédula de Operación Anual, U.S. Greenhouse Gas Reporting Program). These programs typically have very strict reporting requirements.

Project owners and operators might participate in voluntary carbon markets through organizations such as the Climate Action Reserve and Verra; emissions data clearinghouses (e.g., APX, Inc.; IHS Markit); or emissions reductions partnerships with other entities. These organizations will also typically have established reporting requirements.

- **Verification** is an independent assessment of reported GHG emissions and emissions reductions. It is typically undertaken by an independent, third-party verification body to ensure impartial assessment. Verification bodies review reported data, calculation methods, equipment information, and source documentation to ensure that GHGs are reported accurately and conform to requirements of the reporting program. International accreditation forum bodies certify verification bodies to complete GHG verifications. See Appendix D for more information.

Effective MRV is an ongoing process that is repeated throughout the life of a project, often annually.

2.2 What Are the Benefits of Robust Project-Level MRV?

Robust MRV for biogas projects can contribute to several national priorities and objectives (illustrated in Exhibit 5):

Supporting the development of robust emissions inventories. National inventories that use a Tier 1 approach (i.e., based on default values) to estimate emissions can be made more robust by incorporating bottom-up data.[3] For example, a national inventory of manure management that is based on the number of different types of cattle in the country could be adjusted to account for MRV-based data such the capture and use of methane from biogas projects.

See Section 4 for more information on how biogas project MRV can support improvement of national GHG inventories.

- **Enhancing targets, policies, and actions in NDCs.** Under the Paris Agreement, countries set national emissions reductions targets, known as NDCs, and pursue policies, measures, and other actions to meet them. The emissions reductions achieved from these actions are tracked and reported publicly.

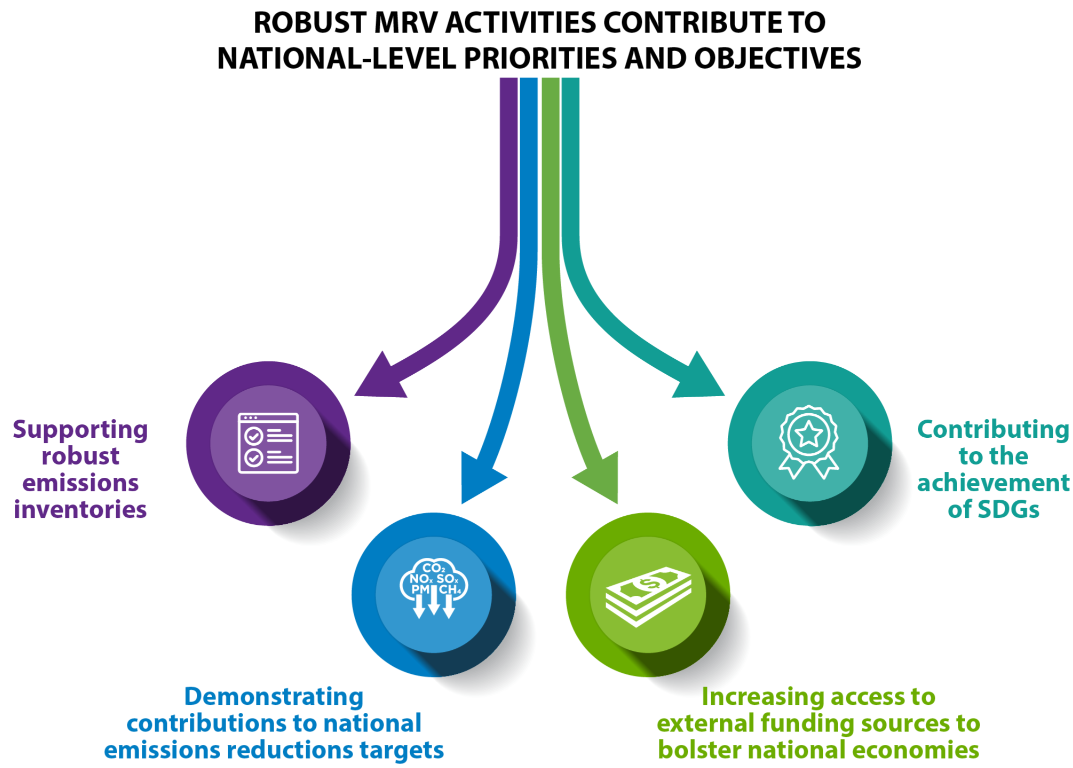
  Although some countries have included specific biogas sector targets in their national goals (e.g., Senegal has set a target for the number of bio-digesters to be installed; IRENA, 2018), the biogas sector is often overlooked; countries typically focus on the largest emissions source sectors such as energy and transportation. However, biogas sector emissions reductions can contribute substantially to national emissions reductions targets; and in some countries, emissions from the biogas sector are rising more rapidly than in other, larger sectors. Robust MRV activities can help demonstrate that the country has met NDC targets as well as showcase the value of incorporating them into NDCs.

  See Section 5 for more information on how project MRV can support enhanced national emissions reductions target setting and commitments.

- **Demonstrating progress toward sustainable development and other national priorities.** As noted above, capturing and using methane can generate considerable economic and social benefits beyond climate change mitigation. These benefits can be tied to United Nations' SDGs. Project-level MRV can provide data to track and demonstrate progress toward these goals. Exhibit 6 illustrates an

3 Tables 2.4 and 2.5 in Chapter 2 of Volume 1 of the *2019 Refinement to the 2006 IPCC Guidelines for Greenhouse Gas Inventories* indicate how governments can approach the inclusion of project-level or facility reported data in the measurement of national emissions or to evaluate emissions reductions.

Exhibit 5. Benefits of Project-Level MRV for National Governments



example of how methane mitigation from landfill gas projects can contribute to a wide range of SDGs.

- Increasing access to external funding sources to promote economic growth. MRV helps ensure that emissions reductions can be quantified, thus enabling project developers to better demonstrate to financiers and funders the prospective and actual mitigation benefits of their investments. For example, the Green Climate Fund incorporates MRV policies and procedures into its structure to help ensure that funding recipients meet emissions mitigation targets.

In addition, MRV activities are fundamental to securing funding through carbon markets, whether they are mandatory or voluntary programs. Carbon markets and emissions trading frameworks each have their own requirements for how emissions reductions should be measured, reported, and verified, but all follow basic MRV principles such as those described in this handbook.

As noted in Exhibit 7, there are several challenges to aligning project-level MRV to achieve the objectives outlined above. The rest of this document and the resources described in the appendices provide information to help address these challenges.

Exhibit 6. Example Linkages between Methane Mitigation from Landfill Gas Projects and SDGs

SDG	Explanation
3 - Good Health and Well-Being	Mitigating methane emissions from landfills results in improved air quality.
6 - Clean Water and Sanitation	Landfill gas projects can help prevent leachate migration into groundwater sources.
7 - Affordable and Clean Energy	Landfill gas provides a source of clean energy.
8 - Decent Work and Economic Growth	Landfill gas projects can create jobs and promote economic development.
12 - Ensure Sustainable Consumption and Production	This goal calls for the development of environmentally sound disposal facilities, such as sanitary landfills with landfill gas collection.
13 - Climate Action	Reducing methane emissions helps reduce global radiative forcing.

Exhibit 7. Challenges to Aligning Project-Level MRV with National Objectives

Aligning project-level MRV with national objectives can be challenging for several reasons:

- Units of measurement, conversion factors, targets, benchmarks, or baseline years, may differ making it difficult to adapt for use in national inventories.
- In many countries, there is no formal mechanism for linking project-level data collection to national GHG inventories or NDC planning frameworks. Such institutional arrangements are critical for effective data sharing.
- National government agencies often do not have dedicated resources or programs to support project-level MRV.
- Financial institutions and other stakeholders have variable requirements for the emissions data that need to be reported, which makes it difficult to streamline programs at the national level.

The resources identified in Appendix A provide information and best practices to support better alignment of project-level MRV and national objectives. Additionally, the Global Methane Initiative offers capacity-building support to countries seeking assistance with developing robust MRV frameworks.

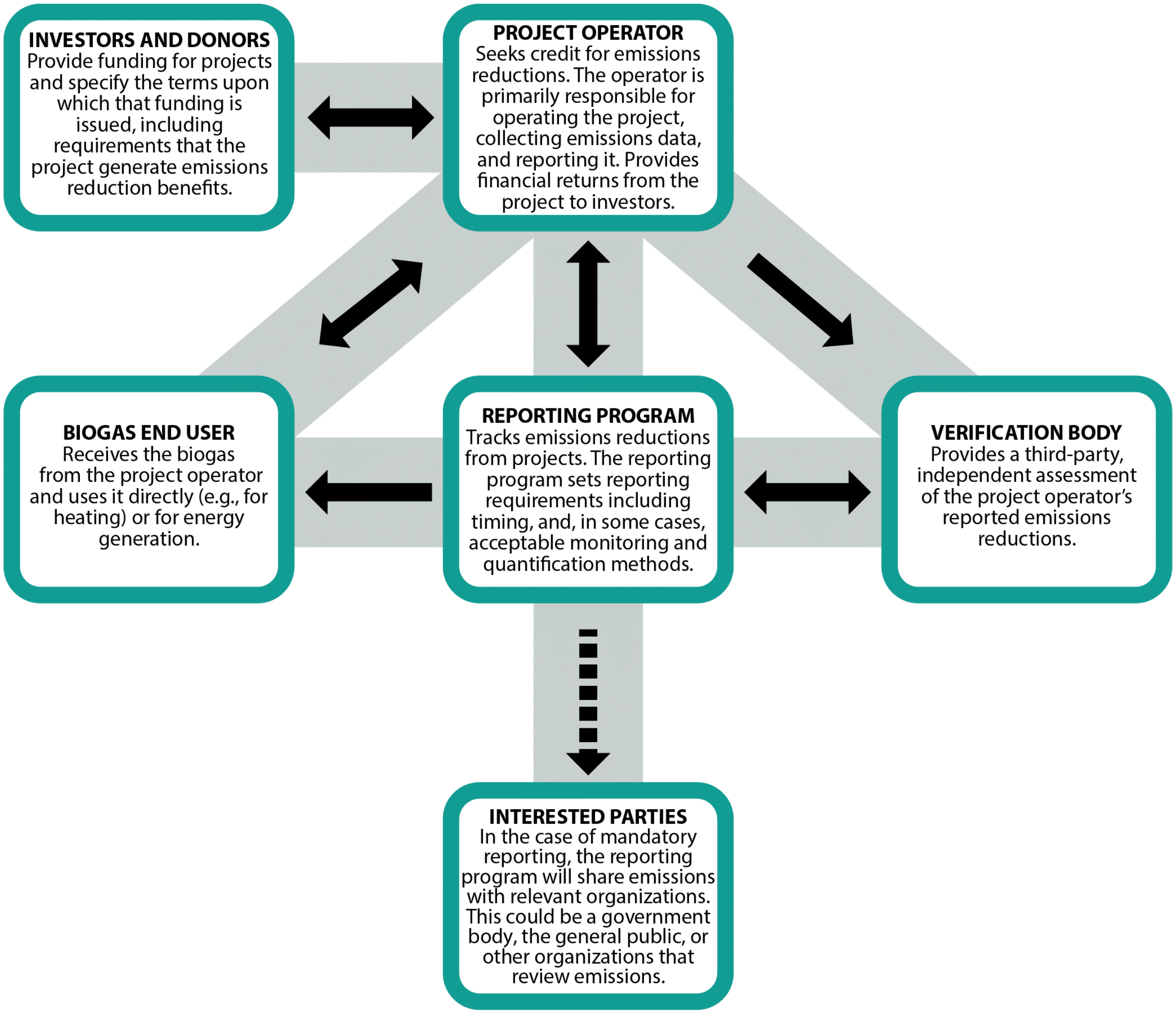
Source: Based on Wilkes et al., 2017.

2.3 Who Are the Key Stakeholders Involved in Project-Level MRV Activities?

A variety of parties and entities are involved in project-level MRV activities, as shown in Exhibit 8. Primary stakeholders who typically communicate and interact with one another during the MRV process include the project operator or proponent, the reporting program, and the verification bodies. Other stakeholders include financers or operators of the mitigation project, as well as any end users of mitigation results or credits (e.g., carbon offsets).

An important objective of planning an MRV system is to clearly outline the lines of communication between all parties involved. In addition, there should be clear delineation of responsibilities and roles for each entity, and the respective data and information that fall under their purview. As discussed in Section 4, these institutional arrangements are particularly important for the purpose of developing robust national GHG inventories.

Exhibit 8. Key Stakeholders in Project-Level MRV in the Biogas Sector and Example Lines of Communication



3. Best Practices for Project-Level MRV in the Biogas Sector

Emissions mitigation projects in the biogas sector include landfill gas recovery for solid waste; and anaerobic digester projects for organic solid waste, agricultural waste, and wastewater. For each of these types of biogas projects, there are common principles and best practices for measuring, reporting, and verifying emissions reductions. Government agencies can use the best practices in this section to develop MRV systems and plans that are tailored toward their specific needs. These principles support the basic requirements of any emissions accounting framework, as identified in Exhibit 9.

Exhibit 9. Basic Requirements for Emissions Accounting

- **Relevance**: Needed for internal and external users, and to determine GHG emissions reductions
- **Completeness**: Include all possible and significant emissions sources in both the baseline and project scenarios
- **Consistency**: Methodology allows for year-to-year and other comparisons
- **Transparency**: Data and clear supporting documentation are available
- **Accuracy**: Meets industry standards (typically +/-5%) and uncertainties are limited as much as possible.

Source: WRI, 2016.

3.1 Measurement

From a bottom-up perspective, the most important component of MRV is the measurement of data. This core component provides the basis for claiming GHG reductions from the action(s) taken.

Developing a Measurement Plan

The main activity for measurement is the collection and management of appropriate data and information to support GHG reductions. Developing and implementing a comprehensive measurement plan is a critical step in this process. A measurement plan provides facility personnel with a blueprint of key steps, including defining what data and information need to be collected (e.g., gas flow rates), how the data and information need to be collected, how data are checked for accuracy, and how to aggregate and summarize the data to determine the GHG reductions achieved. Exhibit 10 presents a summary of key measurement plan elements.

Exhibit 10. Key Elements of a Measurement Plan

- An overview of the facility and operations
- Roles and responsibilities of facility personnel
- A description of the GHG mitigation project/activities
- GHG mitigation project measurement
  - Data and parameters to be collected
  - Onsite equipment used to collect data
  - Data collection process
  - Data management and recordkeeping
  - Quality assurance/quality control (QA/QC) procedures for measurement equipment to ensure data accuracy
- GHG emissions reductions quantification methods and equations.

A measurement plan should be a "living" document that is edited and updated periodically to account for changes in the facility or project activity or emissions estimation methodologies.

Quantifying Emissions Reductions

Quantification Techniques

A critical first step in estimating emissions reductions is establishing a business-as-usual emissions baseline. By developing a baseline, governments are then able to estimate project-level emissions and understand emissions reductions more clearly. Specific factors such as type of disposal (for manure management systems) and climate conditions, including temperature and humidity, could have a significant impact on the baseline estimation. Emissions reductions can then be estimated before project implementation (ex-ante) or after project implementation has begun (ex-post). The following sections describe both types of quantification in general terms. More information about how these types of quantification are applied to specific types of biogas projects (e.g., landfill gas projects) is available in Appendix B.

Ex-Ante Quantification

Ex-ante quantification involves forecasting potential emissions or emissions reductions. These estimates can be useful for projecting emissions reductions as part of a feasibility assessment or project proposal.[4] Ex-ante estimates are based on modeling with assumptions and will have a significant margin of error due to the inherent uncertainty associated with underlying key parameters. This uncertainty could be reduced by using historical values or sampling a subset of the population for key parameters. For example, although biogas generation at a landfill cannot be accurately measured without a biogas collection and metering system, a first order decay (FOD) model is useful for estimating potential methane emissions over time. Annual waste disposal rates at a landfill are used in a FOD model, along with estimated waste decay and per-ton methane generation rates, to forecast methane emissions. Waste disposal rates are commonly tracked by landfills for billing purposes and may be readily available, especially at large landfills. IPCC lists defaults for waste generated on a per-capita basis but using this data has a larger margin of error than using actual waste placement rates at a landfill.

Ex-Post Quantification

Calculating emissions reductions ex-post[5] is important for accurately tracking progress in mitigation efforts. Ex-post measurement is often required for formal emissions reductions reports (e.g., under carbon offsets protocols). Ex-post measurement involves capturing data parameters that can be used to calculate the actual biogas destroyed.

Modeled and measured emissions reductions can vary considerably. For example, measured biogas flows may be greater than modeled emissions due to increased methane production from the digester or the addition of other substrates to the digester. In some cases, reporting programs require a comparison of modeled versus measured results because the estimates can vary so greatly. In such instances, it is good practice to report the lower of the values to avoid overestimation of emissions reductions.

Monitoring methods entail the direct measurement of methane that is destroyed and are only applicable in ex-post scenarios. Modeling methods can be used in both ex-ante and ex-post scenarios – the difference being the use of estimated data versus measured data in the models.

Using Established Methodologies and Tools

Using established national- and sector-level guidance or specific methodologies—such as IPCC guidelines—is considered a best practice. Appendix C provides a list of several tools (such as the one described in Exhibit 11) and methodologies currently available. It is important to note that all guidance and quantification methods will need to be adjusted to specific operations of a facility.

Exhibit 11. EPA's Solid Waste Emissions Estimation Tool

The Solid Waste Emissions Estimation Tool (SWEET) is an MS Excel-based tool that quantifies emissions of methane, black carbon, and other pollutants from sources in the municipal solid waste sector. This tool provides emissions and emissions reductions estimates at the project-, source-, and municipality-level.

Cities can use this information for multiple purposes, including establishing a baseline scenario, comparing a baseline scenario to as many as four alternative scenarios, analyzing specific projects for potential emissions reductions, estimating the contribution of activities in the waste sector to overall city emissions reductions goals, and tracking progress over time, among other things. The tool is based on IPCC emissions inventory methodologies.

For more information, see www.globalmethane.org/SWEET.

4 Ex-ante quantification is based on forecasts and modeling rather than actual measurements.

5 Ex-post quantification is based on real measurements from a project site.

Recent breakthroughs in remote sensing technologies have also demonstrated the feasibility of using satellites to measure methane emissions and may have the potential to accurately measure methane emissions in the future (Cassidy, 2021).

Supporting Documentation

In addition to emissions reductions data, it is important to document:

- Methodologies used to quantify emissions reductions (discussed in more detail in Section 4 and Appendix B)
- GHGs included in the project's scope
- Activity data and how they are measured
- Baseline and any other underlying assumptions
- Sources of uncertainty
- Data sources
- Any data gaps associated with the period for which biogas mitigation efforts are quantified.

Furthermore, any deviations to the methodology used must be identified. Project operators should also demonstrate compliance with the project measurement plan for the respective time period.

GHG Emissions Reductions Quantification Frequency

GHG emissions reductions should be quantified at least annually. During the course of a given measurement period, certain data parameters should be monitored at a frequency that is representative of what is needed to accurately determine emissions reductions, and also be realistic for the project's on-the-ground conditions and expenses. There are tradeoffs when determining the frequency of data collection. For example, requiring methane concentrations of biogas to be monitored by continuous gas analyzers provides a higher level of accuracy of methane concentration in the biogas, but the equipment can be expensive and require more expertise to operate.[6]

On the other hand, taking gas samples monthly or quarterly is much more cost-effective, but would not capture fluctuations in methane concentrations of the biogas due to seasonal variability or project operations.

While less-frequent measurements of methane concentrations are likely to provide sufficient accuracy, a recommended best practice is to install flow meters to provide biogas flow measurements on a continuous or cumulative basis to capture the fluctuations in biogas recovery. Alternatively, project operators can develop targeted sampling strategies that prescribe the best times of the day and season to sample based on an analysis of continuous measurements collected over a discrete period. GHG mitigation programs will typically provide guidance or have requirements on the necessary measurement frequency for data.

Equipment Quality Control

Monitoring equipment (e.g., gas flow meters, gas concentration analyzers, other gas sampling equipment or scales) should be maintained and calibrated following manufacturers' recommendations to increase data accuracy and reduce uncertainties. Conducting accuracy checks on the equipment used in project operations is another best practice. Procedures to complete accuracy checks vary by equipment, but the equipment's accuracy is typically assessed against a known, standard value. Examples include a calibration gas for a gas concentration analyzer or comparing the gas flow meter in use at a project with another flow device to confirm accurate flow readings.

Missing Data Substitution

Monitoring and data recording equipment will often fail or have interruptions during a monitoring period. Frequently, GHG mitigation programs will have specific requirements and methods to substitute for missing data. Without specific guidance, projects should seek to use methods that are reasonable, supported by

6 Anaerobic digestion biogas plants, in general, require highly qualified personnel at the plant with the skills to operate monitoring/measurement equipment.

other data during the measurement period, and are conservative in nature. *IPCC Guidelines for National Greenhouse Gas Inventories* include methods for resolving data gaps using techniques such as overlap, surrogate data, interpolation, and trend extrapolation (IPCC, 2006b). Methods used to substitute missing data should be noted in the measurement plan, and any substitutions for missing data should be clearly articulated.

3.2 Reporting

Reporting is intended to track and store GHG information, and to inform interested parties. Reporting can be handled in many ways – different examples of reporting methods and structures are described below.

Reporting Program

Project operators can report emissions and emissions reductions data to a range of reporting program administrators, depending on the specific objectives. For example, reports might be submitted to national government agencies, as required under national GHG emissions reporting programs; or they might be reported to local governments, as required for developing municipal emissions inventories; or they might be reported to voluntary programs and networks (e.g., CDP, C40 Cities, Global Covenant of Mayors for Climate and Energy). Alternatively, as described in Section 2, the data might be reported to financial institutions or carbon offset program administrators. The reporting requirements and mechanisms will be particular to each program.

Reporting Content

The type of information that must be reported, and the level of detail desired, will vary depending on specific reporting programs. Reporting programs often provide templates to ensure that all necessary information is captured and reported consistently across many projects. Information that is typically required includes:

- Project proponent name and contact information
- Project location
- Time period (i.e., reporting period) for emissions reductions
- Baseline emissions and emissions reductions[7]
- Proposed improvement plan (if required).

Reporting requirements for biogas project types may vary. For example, livestock projects frequently require modeling for emissions reductions calculations in addition to measuring and metering the biogas flows destroyed to calculate emissions reductions. Thus, more reference materials and data may be required.

Reporting Frequency and Timing

The timing and frequency of reporting are usually determined by the reporting program. Aligning with the best practice of quantifying emissions reductions annually, most programs require annual reporting of monitored and quantified GHG emissions. Most programs also have more frequent deadlines for reporting monitoring data. In other programs, the monitoring data are not reported before the completion of verification, when GHG emissions reductions are reported.

3.3 Verification

Verification is intended to provide assurance on the methodologies used to quantify mitigation actions and the quality of data reported. It can also serve as a tool and learning process for mitigation project operators by raising awareness about opportunities for continuous improvement. While verification is a critical component of the MRV process, its costs can be considerable and should therefore be factored into decisions.

7 Some reporting programs may require additional details such as emissions by GHG source, emissions by GHG, average biogas flow, or average methane concentration.

Process

Verification for all biogas subsectors involves the same basic steps, summarized in Exhibit 12 (see Appendix D for more detail). Efforts required to complete the verification may be greater for livestock manure management projects because of the complexity of estimating emissions reductions ex-post using both modeled and metered methods. The level of effort is most affected by project-specific conditions, data management, and the requirements of a particular reporting program.

Exhibit 12. Typical Steps Involved in Verification

1. Receive initial GHG data and documentation
2. Conduct strategic analysis
3. Conduct risk assessment
4. Create/modify risk-based verification and sampling plan
5. Review GHG data and documentation
6. Visit facility/project
7. Develop clarifications or corrective actions
8. Receive additional data and documentation (if needed)
9. Issue verification statement

Third-Party Verification Bodies

As a best practice, GHG data and information should be verified by a third-party verification body, which will ensure impartiality and reduce risks, while increasing the reliability of both data and any emissions offsets as a result of mitigation efforts. In addition, the third-party verification body should be accredited to perform verifications for that applicable sector (e.g., accreditation by an international accreditation forum body for the waste sector). The third-party verification bodies are typically national or international independent entities including, accounting firms, accreditation/certification firms, consulting firms, and law firms. Accreditation of verification bodies ensures that they are competent in the applicable GHG sector to which they are verifying GHG emissions.

Most reporting programs include conflict-of-interest rules. These rules ensure that verification bodies remain impartial and do not have any potential conflicts with the client or project they are verifying. Many programs include a maximum number of reporting periods or years that one verification body can work with a particular project; the most common time limit is six consecutive time periods. This helps to ensure that verification bodies remain free of any conflict and provides opportunities for projects to be reviewed by another third party.

Verification Standard and Criteria

Verifications should be conducted to a verification standard and specified criteria. The standard could be the International Organization for Standardization 14064-3:2019 Greenhouse Gases – Part 3: Specification with Guidance for the Verification and Validation of Greenhouse Gas Statements; or a standard developed specifically for the reporting program or country such as the Clean Development Mechanism Validation and Verification Standard for Project Activities, or the Verified Carbon Standard. Appendix A includes links to these and other MRV standards and protocols.

Two common criteria when conducting verifications are materiality and level of assurance. The materiality threshold is used to identify information that, if omitted or misstated, would significantly misrepresent reported GHG emissions. Materiality thresholds vary across programs, but the UNFCCC "Standard for Applying the Concept of Materiality in Verification (Version 01)" recommends a threshold of +/-5 percent of the total reported emissions reductions [for reductions up to 100,000 tonnes carbon dioxide equivalent (CO_2e) per year] (UNFCCC, 2010). To complete a positive verification, the project's calculation of emissions reductions must fall within the materiality threshold of the verification body's emissions reductions calculation.

The level of assurance refers to the degree of confidence in the data reported. Levels of assurance typically used are *reasonable* and *limited*, with all carbon credit programs requiring reasonable. Materiality and the level of assurance should be considered and identified before beginning verification activities.

Content

The verification must include more than just an assessment of the emissions reductions reported. It should, at a minimum, include an assessment of project boundaries, documentation checks, onsite inspections, a review of measurement and metering methods and equipment, an assessment of data collection and management systems, and an independent calculation of emissions reductions achieved by the project. The approach should be risk-based and focus on aspects of the mitigation project that present a higher risk for error. If verification is conducted for a project that has undergone verification in the past, it is a best practice to review previous verification documents to identify any issues from prior reporting periods.

Frequency

While it is a best practice to report annually, verification could be every other year, every three years, or even less frequently if an initial verification is conducted early in the mitigation project's lifecycle. Another approach would be to conduct a full verification in year one that includes an onsite inspection of the project, with less-intensive verifications conducted remotely in the following years. The frequency of verification is often dictated by the program or at the request of the project developer or owner.

Site Visits

The site visit component of verifications has significant variation among programs. Almost all programs require the project to be physically visited during its initial verification of the measurement period. After this initial visit, requirements for when another visit needs to occur vary widely – some programs require yearly (aligning with an annual verification requirement), while others do not require any additional visits if no substantive project changes (e.g., in equipment, GHG sources, personnel) occur.

4. Using Biogas Project MRV Data to Develop Robust National GHG Inventories

Biogas sector MRV can provide a wealth of data that governments can use to improve their GHG emissions inventories. This section presents several examples of how governments can use project-level MRV data to generate more complete and accurate emissions estimates and reduce uncertainty of estimates.

4.1 GHG Inventory Methodologies for the Biogas Sector

The *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (published in 2006 and subsequently refined, most recently in 2019) provide methodologies for estimating national GHG emissions and sinks. As noted previously, the biogas sector includes municipal solid waste, municipal wastewater, and agriculture emissions sources.[8] Exhibit 13 identifies associated 2006 IPCC Guidelines for the most important sources from a methane mitigation standpoint.

Exhibit 13. Crosswalk of Key Biogas Sector Source Categories and 2006 IPCC Guidelines

Source Category	2006 IPCC Guideline
Solid Waste Disposal	Volume 5, Chapter 3
Manure Management	Volume 4, Chapter 10
Wastewater Treatment	Volume 5, Chapter 6

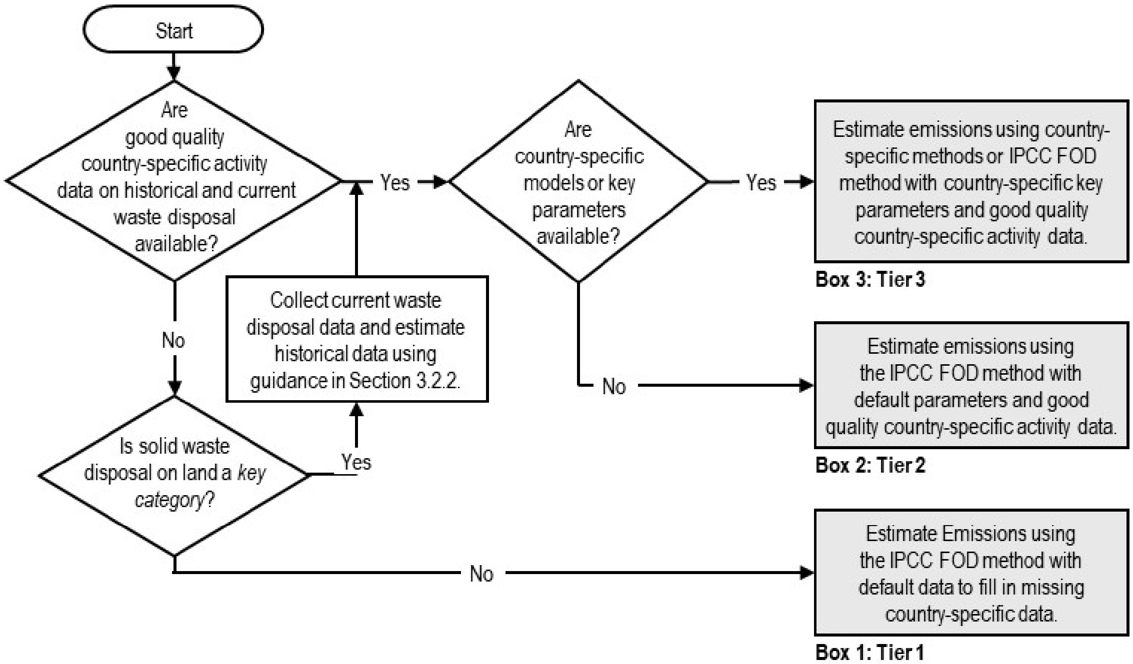
According to the 2006 IPCC Guidelines, there are typically three key methodological considerations for estimating emissions from a particular source. These include the availability and sources of **activity data** and **emissions factors** for each emissions source, and the **choice of method** for estimating emissions:

- **Availability of activity data.** Activity data refer to information about processes that result in emissions or removals over a certain time period (e.g., amount of organic waste sent to a landfill).
- **Availability of emissions factors.** Emissions factors are values that represent a quantity of emissions per unit of activity (e.g., tons of methane emissions per ton of organic waste landfilled).
- **Choice of method.** The 2006 IPCC Guidelines provide three tiers of methods for estimating emissions from a particular sector:
  - Tier 1 methods are based on generic models and default values (e.g., for activities and emissions factors). These methods result in higher uncertainties.
  - Tier 2 methods build on Tier 1 methods, but often include country-specific data (e.g., country-specific activity data), and have lower uncertainties.
  - Tier 3 methods use country- and facility-specific data and tailored models to produce estimates that typically have the lowest uncertainty.

Exhibit 14 presents an example decision tree modified from the 2006 IPCC Guidelines for the solid waste sector. It illustrates a process for selecting appropriate tier methods based on data availability. For example, it illustrates the need for "specific activity data on historical and current waste disposal" in order to use higher tier methods (IPCC, 2006d, page 3.7).

8 Agricultural residues that are treated with other solid waste and not burned are included in the solid waste category.

Exhibit 14. Sample Decision Tree for Selecting a Method to Estimate Methane Emissions from Solid Waste Disposal Sites (modified from IPCC, 2006d, Figure 3.1)



4.2 Leveraging Project-Level MRV to Employ Higher-Tier Methods and Enhance GHG Inventories

Many governments use Tier 1 methods for emissions categories in the biogas sector, often due to limited availability of country-specific data. However, using these methods results in high levels of uncertainty, often +/-50 percent for biogas sector categories. Under the UNFCCC, countries are encouraged to use higher-tier methodologies, especially for key categories (see Exhibit 15).

The following subsections describe opportunities for using data acquired through project-level MRV to advance from Tier 1 to Tier 2 and Tier 3 inventory methods, with the goal of improving accuracy and reducing uncertainty in countries' national GHG emissions estimates. Appendix A includes a list of resources that can be used to implement the strategies described in this section.

Refining Recovery Estimates

In its Second Biennial Update Report to the UNFCCC, the Government of India identified the lack of data on methane recovery from wastewater treatment facilities as a key barrier to improving its GHG inventory (MoEFCC, 2018). Governments can use data on methane recovery from biogas projects to develop nation-specific recovery rates and improve inventories, rather than using generic default values. For example, the IPCC-recommended equation for calculating methane emissions from solid waste disposal sites requires the selection of a methane recovery factor (from landfill gas collection) to subtract from the amount of methane generated (IPCC, 2019a, Equation 3.1). In most cases, the default recovery factor is zero; however, in instances where countries have data on the number of disposal sites with landfill gas recovery, the guidelines recommend using a recovery efficiency rate of 20 percent. If a country were to collect robust MRV data on landfill gas project recovery efficiency, it could use these data to produce a more accurate and country-specific recovery factor.

Exhibit 15. What Constitutes a Key Category?

According to the 2006 IPCC Guidelines (2006a), it is a good practice to identify and prioritize resources on developing inventories of emissions and sinks from "key categories." Countries are encouraged to apply higher-tier methodologies for key categories when possible; when this is not possible, countries are encouraged to take action to improve inventory development processes toward that end. In addition, countries are encouraged to concentrate QA/QC resources on key categories.

Every country will have a different set of key categories. Which ones are considered key depends on a range of factors, including the overall magnitude of emissions from a category, emissions trends, and various qualitative criteria (e.g., the prominence of mitigation technologies and practices in the category). More information on approaches to determining key categories is available in IPCC Guidelines.

In many countries, biogas sector categories are not among the largest emissions sources (although they may be large in some countries); categories in the energy and transportation sectors, for example, are typically much larger contributors to overall emissions. However, based on IPCC Guidelines, it is possible that a category which generates a relatively small quantity of emissions can still be considered key. The guidelines recommend that all categories which cumulatively account for 95% of all emissions be considered key (this is called the "level assessment" approach). In addition, if the trend in emissions from a particular category differs substantially from the trend in overall emissions, that category can be considered key.

As such, it is possible (and common) for biogas sector categories to meet the key category threshold even if they are not typically major sources of emissions overall. For example, methane emissions from waste disposal accounted for only 0.6% of all of India's GHG emissions in 2016, but the category was still considered key based on the level assessment approach (MoEFCC, 2021).

Improving Activity Data

Relying on IPCC default values for activity data contributes a great deal of uncertainty (the guidelines provide suggested uncertainty bounds). For example, in its Third Biennial Update Report, the Government of Chile identified the lack of country-specific activity data as the primary reason why its waste sector emissions have an uncertainty of +/-70 percent (Government of Chile, 2018). Governments can leverage biogas project MRV of emissions to develop better-informed estimates of activities that contribute emissions and practices that avoid them. The 2019 refinement to the 2006 IPCC Guidelines provides further guidance on incorporating facility-level data into national inventories, and states that good quality facility-specific data may be considered and used by national inventory compilers. Facility or project-level data can replace a small subset of inventory data or be used to form a more significant portion of the inventory. For example, estimating emissions from manure management requires specifying the fraction of manure that is handled in management systems (see Equation 10.22 in IPCC, 2019b). Governments can use data compiled from agriculture sector biogas project MRV to develop a country-specific estimate of the fraction of manure for each animal type that is treated in an anaerobic digester, instead of using the default IPCC value (which is typically 0 percent).

Exhibit 16 provides an example of a national project database that is used to support the development of a robust emissions inventory.

Exhibit 16. EPA's Emissions Inventory Methodology for Manure Management

EPA uses methane emissions estimation methodologies for manure management that are in accordance with IPCC (2006) methods. Data inputs include animal populations, the typical animal mass, the proportion of total manure managed in each type of waste management system, volatile solid production rates, the methane production potential of volatile solids, and methane conversion factors. EPA also uses project-level data from the AgSTAR project database to estimate methane emissions from anaerobic digestion systems at livestock operations in the United States. Methane production, collection, and destruction are calculated based on information in the database, and total emissions are then added to the inventory at the state-level.

Source: U.S. EPA, 2020a.

Developing Country-Specific Emissions Factors

Governments can use project-level MRV data to develop country-specific emissions factors for biogas sector sources. According to the 2006 IPCC Guidelines, the best approach to determining emissions factors involves non-invasive or non-disturbing measurements of high-quality emissions data from actual projects or systems representative of those in use in the country. These field results can be used to develop models to estimate emissions factors (Tier 3). This can be especially valuable when the MRV data are based on actual project emissions measurements. For example, project-level monitoring of methane emissions from anaerobic digesters used to process animal manure can be used to inform country-specific emissions factors for the manure management emissions category in a national GHG inventory (IPCC, 2006f).

4.3 Implementation Considerations

When examining opportunities for enhancing GHG inventories through the use of MRV data, governments should be aware of several considerations:

- **Establishing or refining regulatory and institutional arrangements to facilitate data collection and sharing.** Governments might establish or refine legal requirements for projects or facilities to report specific data annually, particularly within sectors where available data are scarce.[9] In some instances, a government might already be collecting project-level MRV data, but there may be a need for a formal arrangement between ministries to facilitate data exchange. In other instances, aggregated data might be available from third parties that will need to agree to share this information, in which case governments may need to develop protocols and policies for data management and security. It is also possible that there is not yet a mechanism for collecting and aggregating data across projects, in which case a government might consider creating a centralized data portal and offering incentives (e.g., recognition) to entities that voluntarily share their data.
- **Analyzing the quality of the data and documenting uncertainties.** Whether using project-level MRV data to refine methane recovery rates, activity data, or emissions factors, it is essential that the data are high quality and representative. For example, a government would not want to use project-level MRV data from projects located only in a specific region to develop a national emissions factor, unless there was a justifiable reason for doing so. Conversely, countries with widely varying climates, agroecosystems, and production technologies may wish to focus on region-specific emission factors. Data quality guidelines and requirements are also critical for ensuring effective incorporation of project-level data into national inventories. In all instances, governments should follow best practices from 2006 IPCC Guidelines for handling uncertainty.
- **Planning improvements.** Governments can plan MRV-based GHG inventory improvements over an extended timeframe. For instance, if a government identifies a particular emissions source's GHG estimates as being highly uncertain, it can develop a plan for implementing MRV-focused efforts to build a body of knowledge that can be used to produce more accurate estimates. For example, in its Second Biennial Update Report, Ghana identified improving its estimates of the fraction of manure managed by different system types as a priority improvement to its inventory (Government of Ghana, 2018).

9 For example, the Ministry of Livestock, Agriculture and Fishery of Uruguay developed the National System of Livestock Information and requires all breeders, intermediates, auction locations, and slaughter plants to register and tag livestock, resulting in full population traceability within the country.

5. Using Biogas Project MRV Data to Enhance Mitigation Targets in NDCs

Biogas project MRV can help inform national mitigation targets in NDCs and enable national governments to better track their progress toward mitigation commitments. This section provides information on NDCs, how governments can use biogas sector MRV to support them, and examples of countries that have included methane-specific goals in their NDCs.

5.1 What are NDCs?

Article 4, paragraph 2 of the Paris Agreement requires that every five years each Party to the Agreement submit a NDC that outlines its efforts to reduce national emissions and achieve the long-term goals set forth in the Paris Agreement (UNFCCC, 2015). Countries' NDCs include several standard components, such as information on the country's current circumstances, the national GHG inventory (both emissions from sources and removal from sinks) by sector, and a description of the specific goals and actions the country will take to reduce GHGs. The NDC may also contain technical information, such as a description of GHG-related reporting methodologies (UNFCCC, 2014). Exhibit 17 highlights the types of information that countries are expected to include with each goal included in their NDCs.

Countries are encouraged to follow a coordinated approach in developing their NDCs to ensure that:

- Comprehensive, country-specific data are used, where available;
- GHG emissions inventories are inclusive of all sectors; and
- Mitigation strategies target critical GHG emissions sources.

The first round of NDCs were submitted in anticipation of and shortly after the adoption of the Paris Agreement in 2015. Countries are asked to update their NDCs every five years, and many did so prior to the 2021 United Nations Glasgow Climate Change Conference. Additionally, the resulting agreement – The Glasgow Climate Pact – requested that countries revisit their 2030 targets in NDCs by the end of 2022 (UNFCCC, 2021). NDCs will be reviewed as part of a global "stocktake" of efforts toward achieving global GHG mitigation targets, the first of which will be conducted in 2023 (and every five years thereafter). By 2024, countries will be required to submit Biennial Transparency Reports to outline updated GHG accounting, progress toward achieving the objectives

Exhibit 17. Type of Information to Be Included for Each Goal of a NDC (modified from UNFCCC, 2020, Figure 8)

- Quantifiable information on the reference point (including, as appropriate, a base year)
- Time frames and/or periods for implementation
- Scope and coverage
- Planning processes
- Assumptions and methodological approaches, including those for estimating and accounting for anthropogenic GHG emissions and, as appropriate, removals
- How the Party considers that its NDC is fair and ambitious in light of its national circumstances
- How the NDC contributes towards achieving the objective of the UNFCCC as set out in its Article 2

set forth in their NDCs, climate impacts and adaptation, and the support needed to achieve NDC goals (UNFCCC, 2020).

5.2 Why Include Methane Emissions Reductions in Updated NDCs?

Emissions reductions proposed in the initial round of NDCs would result in a warming of 2.9°C to 3.4°C above pre-industrial levels over the next century, far from the target of 2.0°C (UNEP, 2018). Meeting the global climate change mitigation targets established under the Paris Agreement will require additional, ambitious emissions reductions from all sectors, not only the largest-emitting sectors (e.g., transport and energy).

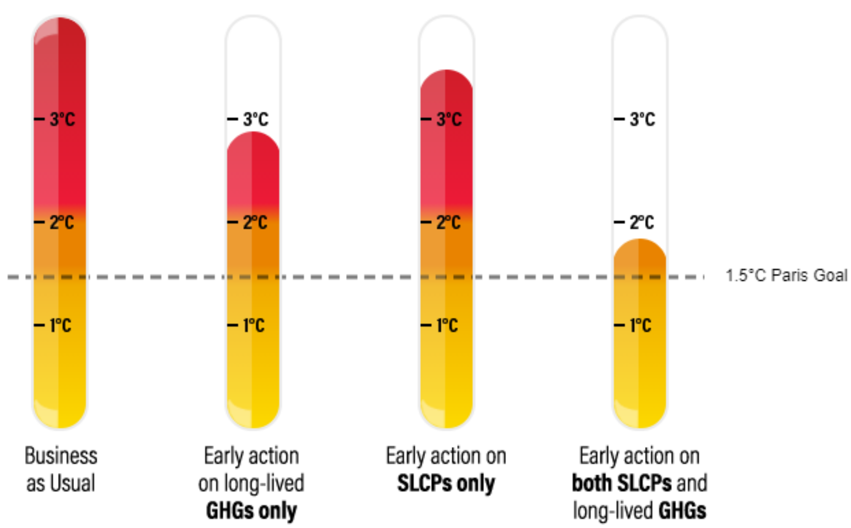
Research indicates that without significant reductions in short-lived climate pollutants (SLCPs), such as methane, global temperature increases will exceed 2.0°C by 2100 (WRI, 2018a; Exhibit 18). As the biogas sector is responsible for approximately 20 percent of anthropogenic methane emissions (GMI, 2020), actions in this sector can play a critical role in meeting global GHG mitigation targets. However, most of the 140 Parties that addressed methane in their first NDC included it only in their overall emissions targets, and not in any specific mitigation strategies to reduce methane in the biogas sector.

5.3 Approaches to Including Methane in NDCs

As governments develop their NDCs, they can consider integrating efforts to mitigate biogas sector methane emissions by:

- Identifying the largest sources of anthropogenic methane emissions in the biogas sector (e.g., landfills, wastewater treatment facilities, agricultural operations). This can be done in concert with the development of national GHG inventories (see Section 4).
- Establishing emissions reductions goals by source category (targets can be a percentage reduction in relation to the baseline year or a specific metric ton reduction). The World Resources Institute (WRI, 2018b) provides several specific examples of goals countries might consider adopting to reduce methane emissions from the biogas sector in their NDCs.
- Identifying specific strategies to mitigate anthropogenic methane by sector and source category (e.g., requiring methane recovery from all

Exhibit 18. Effects of Taking Early Action on SLCPs and Long-Lived GHGs on Global Temperatures by 2100 (WRI, 2018a)



new landfills). The Global Methane Initiative is a source of information on best practices for methane mitigation across the biogas sectors.

- Establishing protocols for measuring methane emissions and emissions reductions for incorporation into national communications (e.g., Biennial Transparency Reports starting no later than 2024). Best practices described in Section 3 and Section 4 and technical details provided in Appendix B can be used to establish rigorous frameworks for collecting project-level MRV data that can improve GHG inventories and tracking of progress toward targets.
- Developing a national database of emissions reductions to more easily track and link project-level data to NDC commitments. For example, Colombia has established a National Registry for the Reduction of GHG Emissions (RENARE) that emissions reductions projects register with and report to; RENARE data will be used to track the country's progress toward Paris Agreement commitments (Minambiente, 2021). A national database also helps ensure that data is in the correct format, and units and conversions are applied consistently. Additionally, a database could assist in the tracing and verification of the end-use of biogas derived fuels for emission reduction credits to avoid double counting.
- Indicating in their NDCs where the country is lacking the resources or capacity required to collect data to make project-level MRV viable.

The availability of accurate and complete data is critical to the development of robust climate mitigation targets and strategies. In the biogas sector, project-level MRV can be a valuable source of data for establishing national emissions reductions baselines and projections.

Section 4 described the importance of institutional arrangements for collecting and reporting MRV data to the national government for the purpose of developing GHG inventories. These arrangements can be leveraged to collect data for the purpose of analyzing mitigation pathways as well.

5.4 Examples of Countries that Have Included Methane Targets in Their NDCs

Several countries, including those mentioned below, have included methane emissions mitigation targets in their NDCs. Project-level MRV can help demonstrate these countries' progress toward achieving these quantitative targets.

Rwanda

Rwanda's first NDC highlighted the need for action in the solid waste sector. This NDC described the growth in waste-related methane emissions under a business-as-usual scenario. To help address this challenge, the country set a target of reducing landfill methane emissions by approximately 600,000 tonnes CO_2e by 2030. It intends to do this by instituting regulations on landfill emissions and using landfill gas collection and utilization (Government of Rwanda, 2015).

Dominica

Dominica's NDC includes a goal of reducing emissions from the solid waste sector by 78.6 percent by 2030, which it will achieve by addressing methane emissions from its existing landfill. Methane generated at the landfill is currently vented. The country proposes to reduce methane emissions at the site by increasing organic waste diversion and installing a flaring system (Government of Dominica, 2015).

Uruguay

Uruguay's NDC presents both conditional and unconditional methane mitigation objectives, with an unconditional 57 percent reduction in methane emissions intensity per gross domestic product unit from base year 1990 by 2025, and a conditional 59 percent reduction. In the waste sector, unconditional objectives will be met through the introduction of methane capture and flaring in solid urban waste final disposal systems. The NDC includes an unconditional target of disposing 60 percent of urban solid waste in landfills that capture and flare or use methane by 2025 (Government of Uruguay, 2017).

6. Summary

Accounting for methane and other SLCPs is essential for meeting international climate change targets. Actions in the biogas sector, which is responsible for 20 percent of anthropogenic methane emissions, can contribute significantly to achieving these goals. Project-level MRV is critical for linking bottom-up emissions quantification in the biogas sector with top-down inventory methodologies. It allows governments to develop more robust inventories, plan mitigation actions, demonstrate measurable progress toward achieving mitigation targets and other objectives (e.g., SDGs), and can lead to increased access to funding for biogas projects.

Historically, governments have struggled to account for emissions reductions from biogas projects, in part due to limited access to clear guiding principles for emissions MRV. This handbook was designed to address that need and provide government decision-makers and other stakeholders with best practices and steps involved in the MRV process. The appendices that follow provide more detailed support on MRV resources, emissions measurement techniques, quantification tools, and verification best practices.

Bibliography

Basak, R. 2016. Monitoring, reporting, and verification requirements and implementation costs for climate change mitigation activities: Focus on Bangladesh, India, Mexico, and Vietnam. CCAFS Working Paper no. 162. CGIAR Research Program on Climate Change, Agriculture, and Food Security (CCAFS). Copenhagen, Denmark. Available: https://cgspace.cgiar.org/bitstream/handle/10568/75661/CCAFS%20Working%20Paper%20162%20Basak%20MRV%20requirements%20and%20implementation%20costs%20for%20mitigation.pdf.

Cassidy, E. 2021. From Cow Manure to Landfills: Mapping Methane Emissions in California. EarthData. Available: https://earthdata.nasa.gov/learn/articles/mapping-methane-in-california.

CCAC. (n.d.). Methane. Climate & Clean Air Coalition. Available: https://www.ccacoalition.org/en/slcps/methane.

CCAC. 2019. The Multiple Benefits Pathway Framework – Methodology Briefing. Climate & Clean Air Coalition. Available: https://www.ccacoalition.org/en/file/7028/download?token=QNv32kXI.

Climate Watch. 2021. Query of NDCs for references to "methane." Available: https://www.climatewatchdata.org/ndc-search?document=first_ndc&query=%22methane%22&searchBy=query.

EESI. 2013. Short Lived Climate Pollutants: Why Are They Important? Environmental and Energy Study Institute. Available: https://www.eesi.org/files/FactSheet_SLCP_020113.pdf.

GMI. 2020. About Methane. Global Methane Initiative. Available: https://www.globalmethane.org/about/methane.aspx.

Government of Chile. 2018. Chile's Third Biennial Update Report. Available: https://unfccc.int/sites/default/files/resource/5769410_Chile-BUR3-1-Chile_3BUR_English.pdf.

Government of Dominica. 2015. Nationally Determined Contribution. Available: https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Dominica%20First/Commonwealth%20of%20Dominica-%20Intended%20Nationally%20Determined%20Contributions%20(INDC).pdf.

Government of Ghana. 2018. Ghana's Second Biennial Update Report. Available: https://unfccc.int/sites/default/files/resource/gh_bur2_rev-2.pdf.

Government of Rwanda. 2015. Intended Nationally Determined Contribution. Available: https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Rwanda%20First/INDC_Rwanda_Nov.2015.pdf

Government of Uruguay. 2017. Nationally Determined Contribution. Available: https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Uruguay%20First/Uruguay_First%20Nationally%20Determined%20Contribution.pdf.

IPCC. 2006a. *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 1, Chapter 4.* Intergovernmental Panel on Climate Change. Available: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/1_Volume1/V1_4_Ch4_MethodChoice.pdf.

IPCC. 2006b. *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 1, Chapter 5.* Intergovernmental Panel on Climate Change. Available: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/1_Volume1/V1_5_Ch5_Timeseries.pdf.

IPCC. 2006c. *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5, Chapter 2*. Intergovernmental Panel on Climate Change. Available: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_2_Ch2_Waste_Data.pdf.

IPCC. 2006d. *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5, Chapter 3*. Intergovernmental Panel on Climate Change. Available: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf.

IPCC. 2006e. *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5, Chapter 6*. Intergovernmental Panel on Climate Change. Available: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf.

IPCC. 2006f. *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, Chapter 10*. Intergovernmental Panel on Climate Change. Available: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf.

IPCC. 2019a. *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5, Chapter 3.* Intergovernmental Panel on Climate Change. Available: https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/5_Volume5/19R_V5_3_Ch03_SWDS.pdf.

IPCC. 2019b. *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, Chapter 10.* Intergovernmental Panel on Climate Change. Available: https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch10_Livestock.pdf.

IPCC. 2019c. *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 1, Chapter 1.* Intergovernmental Panel on Climate Change. Available: https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/1_Volume1/19R_V1_Ch01_Introduction.pdf.

IRENA. 2018. Assessment of the Renewable Energy Components in Nationally Determined Contributions: The Methodology. International Renewable Energy Agency. Available: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Nov/IRENA_NDC_methodology_2018.pdf?la=en&hash=4E6E9173BB306CDD4295F1E7F5FB1CF477CEAAF5.

Minambiente. 2021. RENARE, the platform to record greenhouse gas reductions in Colombia. Ministry of Environmental and Sustainable Development, Government of Columbia. Available: https://www.minambiente.gov.co/index.php/noticias/4497-renare-plataforma-para-registrar-reducciones-gases-efecto-invernadero.

MoEFCC. 2018. India: Second Biennial Update Report to the United Nations Framework Convention on Climate Change. Ministry of Environment, Forest and Climate Change, Government of India. Available: https://unfccc.int/sites/default/files/resource/INDIA%20SECOND%20BUR%20High%20Res.pdf.

MoEFCC. 2021. India: Third Biennial Update Report to the United Nations Framework Convention on Climate Change. Ministry of Environment, Forest and Climate Change, Government of India. Available: https://unfccc.int/sites/default/files/resource/INDIA_%20BUR-3_20.02.2021_High.pdf.

Pachauri et al. 2014. Climate Change 2014 Synthesis Report. Intergovernmental Panel on Climate Change. Available: https://www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf.

UNEP. 2018. Emissions Gap Report 2018. United Nations Environment Programme. Available: https://wedocs.unep.org/bitstream/handle/20.500.11822/26895/EGR2018_FullReport_EN.pdf?isAllowed=y&sequence=1.

UNFCCC. 2008. Report of the Conference of the Parties on its thirteenth session, held in Bali from 3 to 15 December 2007. Addendum. Part Two: Action taken by the Conference of the Parties at its thirteenth session. United Nations Framework Convention on Climate Change: Available: https://unfccc.int/documents/5079.

UNFCCC. 2010. Standard for Applying the Concept of Materiality in Verifications (Version 01). United Nations Framework Convention on Climate Change. Available: https://ji.unfccc.int/Ref/Documents/Materiality.pdf.

UNFCCC. 2014. Handbook on Measurement, Reporting and Verification for Developing Country Parties. United Nations Framework Convention on Climate Change. Available: https://unfccc.int/files/national_reports/annex_i_natcom_/application/pdf/non-annex_i_mrv_handbook.pdf.

UNFCCC. 2015. Paris Agreement. United Nations Framework Convention on Climate Change. Available: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement.

UNFCCC. 2020. Reference Manual for the Enhanced Transparency Framework under the Paris Agreement: Understanding the Enhanced Transparency Framework and Its linkages to Nationally Determined Contribution Accounting. United Nations Framework Convention on Climate Change. Available: https://unfccc.int/sites/default/files/resource/ETFReferenceManual.pdf.

UNFCCC. 2021. Glasgow Climate Pact. United Nations Framework Convention on Climate Change. Available: https://unfccc.int/sites/default/files/resource/cma2021_L16_adv.pdf

U.S. EPA. 2020a. Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990–2018. United States Environmental Protection Agency. Available: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2018.

U.S. EPA. 2020b. Overview of Greenhouse Gases. United States Environmental Protection Agency. Available: https://www.epa.gov/ghgemissions/overview-greenhouse-gases.

Wilkes, A., A. Reisinger, E. Wollenberg, and S. van Dijk. 2017. Measurement, Reporting and Verification of Livestock GHG Emissions by Developing Countries in the UNFCCC: Current Practices and Opportunities for Improvement. CCAFS Report No. 17. Available: www.ccafs.cgiar.org.

WRI. 2016. MRV 101: Understanding Measurement, Reporting, and Verification of Climate Change Mitigation. World Resources Institute. Available: https://wriorg.s3.amazonaws.com/s3fs-public/MRV_101_0.pdf?_ga=2.35539809.1522233951.1559164559-2009947254.1557184251.

WRI. 2018a. 3 Charts Explain One of the Most Overlooked Opportunities to Address Climate Change and Poverty. World Resources Institute. Available: https://www.wri.org/blog/2018/10/3-charts-explain-one-most-overlooked-opportunities-address-climate-change-and-poverty.

WRI. 2018b. Strengthening Nationally Determined Contributions to Catalyze Actions that Reduce Short-Lived Climate Pollutants. World Resources Institute. Available: https://www.wri.org/publications/reducing-SLCPs?downloaded=true.

Appendix A. Helpful Resources

Exhibit A.1. MRV Resources

Title	Organization	Date	Audience	Description	Link
Handbook on Measurement, Reporting and Verification for Developing Country Parties	UNFCCC	2014	Climate change practitioners	This handbook provides detailed information and instructions on the obligations a country has on MRV, including timing and content requirements for communications per UNFCCC policy. It includes a template for reporting, instructions for seeking technical support, and many graphics on how MRV components fit together.	https://unfccc.int/files/national_reports/annex_i_natcom_/application/pdf/non-annex_i_mrv_handbook.pdf
MRV Platform for Agriculture	Global Research Alliance for Agricultural Greenhouse Gases; the CGIAR Research Program on Climate Change, Agriculture and Food Security; Unique Forestry and Land Use; and the New Zealand Government	n.d.	Policymakers; climate change practitioners	This website includes a variety of resources for MRV in the agricultural sector, including case studies, databases, technical tools, guidance, and academic journal articles.	https://www.agmrv.org/
RALI GHG MRV Harmonization Framework	United States Agency for International Development	2019	National inventory compilers; mitigation activity implementers; other climate change practitioners	This report is a step-by-step guide for using the top-down and bottom-up "Harmonization Framework" for conducting GHG accounting, determining GHG mitigation efforts, and implementing MRV practices.	https://www.climatelinks.org/resources/rali-ghg-mrv-harmonization-framework
Initial Monitoring and Accountability Framework for Accredited Entities	Green Climate Fund	2015	National policymakers and practitioners	This document documents a decision from a Green Climate Fund Board meeting and spells out rules for keeping Accredited Entities (which support Parties' efforts) in compliance with monitoring and reporting their GHG emissions.	https://www.greenclimate.fund/documents/20182/76153/DECISION_B.11_10_-_Initial_monitoring_and_accountability_framework_for_accredited_entities.pdf/b06dddfc-2d18-4675-9d2f-d3e81de6ba99

Title	Organization	Date	Audience	Description	Link
MRV 101: Understanding Measurement, Reporting, and Verification of Climate Change Mitigation	WRI	2016	National policymaker; practitioners; NGOs	This report introduces three approaches to MRV for GHG mitigation efforts, including methodology and data requirements.	https://wriorg.s3.amazonaws.com/s3fs-public/MRV_101_0.pdf
"MRV In Practice" – Connecting Bottom-Up and Top-Down Approaches for Developing National MRV Systems for NDCs	First Climate Consulting and UN Development Programme	2018	National and sub-national policymakers in least-developed countries and small island nations; development organizations; research institutions; NGOs; consultants	This report offers advice for developing and refining MRV systems, based on UNFCCC requirements.	https://www.transparency-partnership.net/system/files/document/GH_New%20Climate_MRV%20in%20Practice_2018.pdf
Partnership on Transparency in the Paris Agreement: National Benefits of Climate Reporting	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) on behalf of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Federal Republic of Germany)	2018	National policymakers	This report explains the benefits of MRV to countries, such as tracking progress toward SDGs, public engagement, and access to funding.	https://www.international-climate-initiative.com/fileadmin/Dokumente/2018/180917_Information_Matters_National_benefits_of_climate_reporting.pdf
Measurement, Reporting and Verification of Livestock GHG Emissions by Developing Countries in the UNFCCC	Climate Change, Agriculture and Food Security, Global Research Alliance Food and Food and Agriculture Organization of the United Nations, with support from the New Zealand government, the United States Agency for International Development, and the World Bank	2017	National policymakers in developing countries	This brief makes recommendations for improving MRV methods for emissions in the livestock sector.	https://cgspace.cgiar.org/bitstream/handle/10568/89335/CCAFS_Report17.pdf
Reference Document on Measurement, Reporting and Verification in the Transport Sector	The TRANSfer project is implemented by GIZ and financed by the International Climate Initiative of the German Ministry for the Environment, Nature Conservation, Building and Nuclear Safety	2014	Policymakers; climate change practitioners; transportation experts	This report describes approaches for MRV in the transportation sector and includes case studies.	http://transferproject.org/wp-content/uploads/2014/10/Reference-Document_Transport-MRV_final.pdf

Exhibit A.2. Resources for GHG Inventories and NDCs

Title	Organization	Description	Link
2006 IPCC Guidelines for National GHG Inventories	IPCC	The IPCC provides guidelines for developing national GHG inventories, with specific volumes by sector, including the agricultural and waste sectors.	https://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html
2019 Refinement to the 2006 IPCC Guidelines for National GHG Inventories	IPCC	The IPCC provides guidelines for developing national GHG inventories, with specific volumes by sector, including the agricultural and waste sectors.	https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html
IPCC Inventory Software	IPCC	This software helps users conduct GHG inventories according to IPCC methods. It includes Tier 1 (i.e., simpler) methods for all sectors; and Tier 2 (i.e., more complex) methods for energy, industrial processes, waste, and agriculture.	https://www.ipcc-nggip.iges.or.jp/software/index.html
Livestock Activity Data Guidance (L-ADG): Methods and Guidance on Compilation of Activity Data for Tier 2 Livestock GHG inventories	Food and Agriculture Organization of the United Nations, and Global Research Alliance on Agricultural Greenhouse Gases	This document provides information to help countries improve the accuracy of livestock emissions estimates in national GHG inventories and enables them to measure and report progress toward their NDCs.	https://ccacoalition.org/en/resources/livestock-activity-data-guidance-l-adg
National GHG Inventory Capacity Building Toolkit	EPA Climate Change Division	This webpage provides templates and technical assistance tools for download to help countries develop GHG inventory systems that are consistent with IPCC and UNFCCC guidelines.	https://www.epa.gov/ghgemissions/toolkit-building-national-ghg-inventory-systems
Agriculture and Land Use National Greenhouse Gas Inventory (ALU) Software	Colorado State University	The ALU software is a tool for GHG inventory of the Agriculture, Forestry and Other Land Use sector and is applicable at national and project levels. The software is based on the methods in the IPCC National GHG Inventory Guidelines, for both Tier 1 and Tier 2 methods. The software is also designed to support an evaluation of mitigation potentials in this sector, including emissions from livestock manure management.	https://www.nrel.colostate.edu/projects/alusoftware/home
Opportunities for Increasing Ambition of NDCs through Integrated Air Pollution and Climate Change Planning	Climate and Clean Air Coalition	This document provides guidance on identifying, prioritizing, and incorporating SLCP mitigation measures into updated NDCs, including methane.	https://www.ccacoalition.org/en/resources/opportunities-increasing-ambition-nationally-determined-contributions-through-integrated
Strengthening Nationally Determined Contributions to Catalyze Actions that Reduce Short-Lived Climate Pollutants	WRI	This document provides guidance and examples to support incorporation of SLCPs, including methane, into NDCs.	https://www.wri.org/publications/reducing-SLCPs?downloaded=true

Exhibit A.3. MRV Protocols and Standards

Title	Organization	Description	Link
Climate Action Reserve Protocols	Climate Action Reserve	This website provides downloadable protocols and links to technical resources for GHG emissions reductions projects in various sectors, landfills, waste digestion, and agriculture. They are intended for use by project developers to generate emissions reductions projects and credits.	http://www.climateactionreserve.org/how/protocols/
California Air Resources Board Compliance Offset Protocols: Livestock Project	California Air Resources Board	This website provides methods to quantify and report GHG emission reductions associated with the installation of a biogas control system (BCS) for manure management on dairy cattle and swine farms. The focus of the protocol is on the quantification of the change in methane emissions, while accounting for effects on carbon dioxide emissions.	Livestock Projects | California Air Resources Board
The Climate Registry Protocol	The Climate Registry	This website offers general reporting and verification protocol and emissions factors, as well as some sector-specific resources. It is intended for companies that voluntarily report their GHG emissions.	https://www.theclimateregistry.org/tools-resources/reporting-protocols/general-reporting-protocol
Gold Standard: Agriculture Methodologies	Gold Standard	This webpage includes a few different step-by-step GHG methodologies for the agricultural sector. They are intended for use by project developers to generate emissions reductions projects and credits.	https://www.goldstandard.org/resources/agriculture-requirements
Gold Standard: Energy Methodologies	Gold Standard	This webpage includes a few different step-by-step GHG methodologies for the energy sector. They are intended for use by project developers to generate emissions reductions projects and credits.	https://www.goldstandard.org/resources/energy-requirements
Gold Standard: Forest Methodologies	Gold Standard	This webpage includes a methodology for the forestry sector. They are intended for use by project developers to generate emissions reductions projects and credits.	https://www.goldstandard.org/resources/afforestation-reforestation-requirements
Greenhouse Gas Protocol Policy and Action Standard	Greenhouse Gas Protocol	This report offers a standardized process for conducting MRV for efforts resulting from government policies related to GHG emissions reduction. It is written for policymakers and policy analysts who are evaluating government actions.	https://ghgprotocol.org/policy-and-action-standard
Carbon Accounting: Standards and Methodologies	American Carbon Registry	This website provides downloadable protocols and links to technical resources for GHG emissions reductions projects in various sectors, including those for landfill gas. They are intended for use by project developers to generate emissions reductions projects and credits.	https://americancarbonregistry.org/carbon-accounting/standards-methodologies
Verified Carbon Standard Methodologies	Verra	This website provides downloadable protocols and links to technical resources for GHG emissions reductions projects in various sectors, including the waste and agriculture sectors. They are intended for use by project developers to generate emissions reductions projects and credits.	https://verra.org/methodologies/

Appendix B. Project Type-Specific Emissions Measurement Techniques

Emissions that are estimated or forecast before project implementation are referred to as ex-ante estimates, and emissions measured or calculated after project implementation are referred to as ex-post measurements. While ex-ante emissions reductions are always modeled, ex-post measurements can be conducted by monitoring on site with equipment and by modeling using information about the project. This appendix describes ex-ante and ex-post methods used in the following biogas sector project types:

1. Landfill gas capture and utilization projects (Section B.1)
2. Organic waste diversion and methane avoidance (Section B.2)
3. Livestock waste diversion to anaerobic digesters (Section B.3)
4. Municipal wastewater biogas (Section B.4).

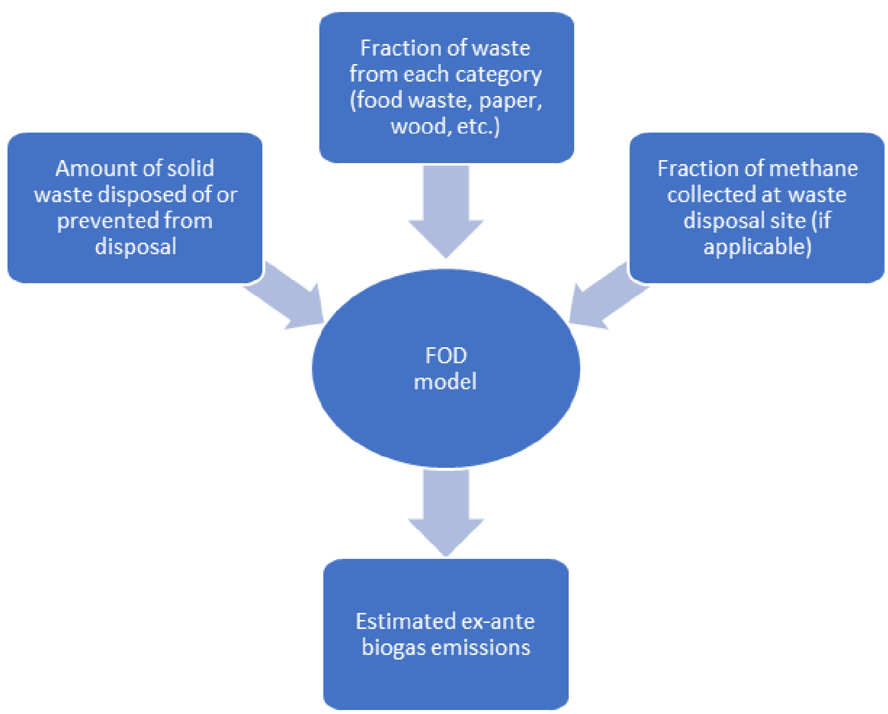
This appendix provides a list of tools and resources to assist in quantifying emissions based on the techniques described below.

B.1 Landfill Gas Capture and Utilization Projects

Ex-Ante Estimates of Emissions Reductions

A first order decay (FOD) model is used to estimate biogas production at a solid waste disposal site on an ex-ante basis (Exhibit B.1), and to estimate biogas emissions that could be avoided either from the displacement of waste or potential biogas destruction (discussed in Section B.2). For biogas destruction, estimates of biogas production from a FOD model often are significantly different than the actual biogas collected and destroyed. The primary cause of these significant variations is usually the inability of default input parameters used in a FOD model to account for site-specific conditions affecting methane generation and emissions, which vary with changes to system design and efficiency, climatic conditions, and waste amounts and composition.

Exhibit B.1. FOD Model Inputs



Important data parameters for a FOD model include:

- Annual mass of total waste sent to (or diverted from) landfills
- Waste composition (percentages and types of organic waste)

- Climatic conditions (wet climates promote faster waste decay and rates of biogas production than dry climates)
- Whether the landfill has an active landfill gas collection system (for calculating the baseline scenario)
- Managed or unmanaged landfills (e.g., open dump).[10]

Availability of these data can vary widely between countries based on typical waste management practices. If the total waste disposed of and the waste management type are not available, these parameters can be estimated based on IPCC default factors. Waste composition data may be available from local or regional waste composition studies. Otherwise, IPCC defaults can be used (see Volume 5, Chapter 2 of the 2006 IPCC Guidelines, 2006c, 2019a). For example, IPCC lists default values of waste generation and methods of disposal in Asia (see Table 2.1 in the 2006 IPCC Guidelines, 2006c, 2019a). However, it is good practice that countries use site-specific data for municipal solid waste generation, composition, and management practices to determine GHG emissions. Some municipalities may require the reporting of waste disposal at landfills in their jurisdiction.

Quantifying Ex-Post Emissions Reductions

Once a biogas mitigation effort is in place through a landfill gas collection and destruction system, quantifying emissions reductions involves measuring the following components:

- Total volume of biogas sent to a destruction device (flare, engine, boiler, etc.) via a biogas flow meter
- Temperature and pressure readings of the biogas (unless the flow meter internally corrects for these parameters)
- Methane composition (continuous, weekly, monthly, or quarterly measurements)
- Additional energy needed to support project activities
- A programmable logic controller that automatically records data points at specified intervals.

Emissions reductions quantification requires estimating or calculating the following:

- Destruction efficiency of the combustion device (flare, engine, boiler, etc.)
- Modeled biogas generation rates to estimate the amount of uncollected biogas
- Percent oxidation in soil of the uncollected methane
- Actual amount of biogas collected and destroyed before project implementation and/or estimated amount of biogas recovery required by regulations.

The destruction efficiency of the biogas destruction device could also be measured; however, default destruction efficiencies are sufficiently accurate and are generally accepted by mitigation programs.

B.2 Organic Waste Diversion and Methane Avoidance

Ex-Ante Estimates of Emissions Avoided

Estimating emissions avoided from waste displacement uses the same FOD model used to estimate the ex-ante solid waste biogas potential discussed in Section B.1. The key difference is that because the waste is not disposed

---

10 Open dumps with shallow waste depths and limited cover produce significantly less biogas. Managed landfills can reduce methane emissions by promoting oxidation in cover soils, and collecting and combusting biogas.

of in the landfill but sent to a composting operation or digester, it is not possible to measure the biogas that would have been produced in the absence of a mitigation project. Instead, a FOD model estimates biogas mitigation potential based on methane generation from the annual amounts of waste not sent to a landfill during the monitored period. Refer to Section B.1 for estimating the biogas mitigation potential for solid waste disposal in landfills.

Ex-Post Quantification of Emissions Avoided

Estimating emissions avoided from waste diversion involves measuring the following key parameters:

- Total weight of waste diverted from a landfill to an anaerobic digester facility
- Composition of diverted waste
- Energy required to operate the diversion project facility
- If indirect emissions reductions from the use of diverted materials for manufacturing or energy production are being considered, estimate emissions factors per tonne of utilized materials
- Amount of biogas destroyed at the landfill that waste was diverted from if it employs a gas collection and control system.

The quantification of emissions reductions from diverting waste from disposal also requires employing the emissions estimation tools used for ex-ante estimates of biogas that would have been produced by organic wastes. It is important to note that biogas abatement from waste diversion is significantly lower at landfills already employing gas collection systems because the baseline scenario assumes biogas mitigation is already occurring.

B.3 Livestock Waste Diversion to Anaerobic Digesters

Ex-Ante Estimates of Emissions Reductions

Similar to solid waste, calculating ex-ante biogas emissions from livestock waste management uses modeling to estimate biogas emissions that could be avoided either from biogas destruction on site or avoided biogas production from removing solids in the waste stream, or both activities implemented together (a solid separator located before or after a covered lagoon that collects and destroys biogas are two separate activities avoiding biogas emissions).

Volume 4, Chapter 10 of the 2006 IPCC Guidelines (2006f, 2019b) includes the equation consistently used by many GHG reduction programs to estimate methane emissions from manure management. Important data parameters for this model include:

- Type and number of livestock whose waste is managed in the manure system (e.g., for a dairy farm, milking cows, dry cows, heifers, calves, bulls)
- Methane conversion factor for the manure treatment system
- Fraction of manure from each livestock category managed in the treatment system
- Animal weight (measured or default)
- Volatile solid excretion (default or testing)
- Maximum methane-producing capacity of each livestock type (default typically)

- Average ambient temperature
- Other manure management practices already occurring before project initiation (i.e., baseline).

Ex-Post Quantification of Emissions Reductions

Ex-post emissions at a biogas destruction project can be determined by modeling using the same parameters discussed above or by measuring the actual biogas destruction from an anaerobic digester. In most cases, the more conservative of the two emissions reductions values is taken as the end result. This check is necessary because diverting waste to an anaerobic digester can artificially increase methane production that would have not occurred in the baseline scenario. For example, a project in a cold location that sends waste to a heated digester in the winter is a significantly different situation than if that same waste were sent to an uncovered anaerobic lagoon in freezing conditions.

For the modeled portion of this comparison, the parameters noted above would also need to be measured. In addition, any project emissions from the combustion of the biogas (e.g., uncombusted methane, venting events, and emissions from fossil fuels/electricity) would need to be subtracted from the modeled emissions.

For the measured emissions reductions, the following items would need to be monitored:

- Biogas flow
- Methane concentration of biogas (continuous, weekly, monthly, or quarterly measurements)
- Destruction efficiency of devices (typically default values or based on site-specific testing)
- Destruction device operability (to ensure destruction of biogas)
- Venting events
- Consumption of fossil fuels and electricity due to project activities.

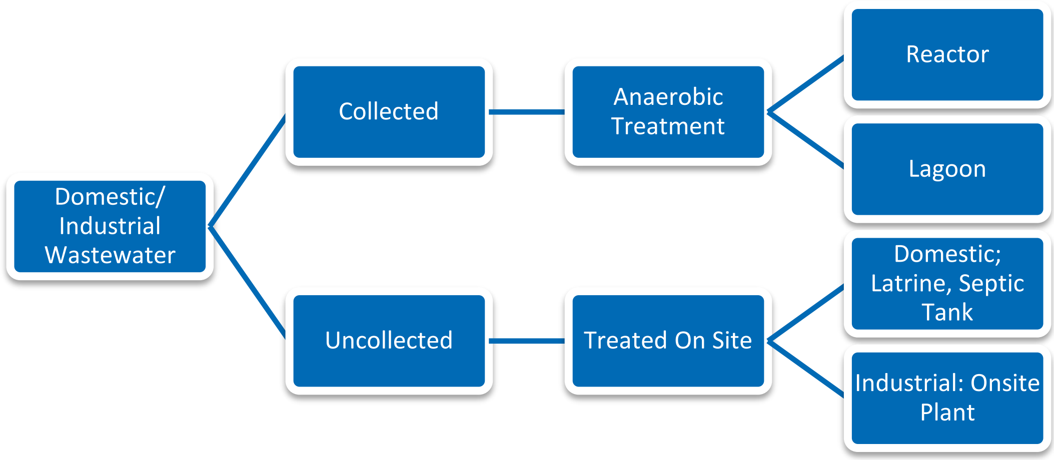
B.4 Municipal Wastewater Biogas

The main GHGs from wastewater treatment are methane and nitrous oxide. Nitrous oxide emissions evolve from the nitrification/de-nitrification cycle and is outside the scope of this discussion. Biogas is generated in anaerobic environments and in the disposal of wastewater in large bodies of water or aerobic environments that do not produce significant amounts of biogas.

The decision tree in Exhibit B.2, which was adapted from IPCC and simplified to highlight significant potential sources of methane generation, can be used to classify regional treatment systems on a granular basis (see Figure 6.1 in the 2006 IPCC Guidelines, 2006e). This decision tree can be used to target the largest potential biogas emissions sources in the wastewater sector. If the wastewater treatment system under consideration falls into one of the four final categories, it is likely a target for biogas mitigation. One exception would be an anaerobic reactor already collecting and destroying biogas.

The largest emissions avoidance potential is likely from anaerobic lagoons, industrial wastewater treated on site, and uncollected methane from anaerobic reactors. Consideration should also be given to abatement efforts that can be easily implemented (e.g., collecting venting methane from an anaerobic reactor is a proven technology and can be used to produce energy), as this would be a much easier target for abatement opposed to developing a collection system in a rural area.

Exhibit B.2. Ex-Ante Decision Tree for Targeting Significant Biogas Emissions Sources from Municipal Wastewater (adapted from IPCC, 2006e, Figure 6.1)



Ex-Ante Estimates of Emissions Reductions

One advantage of biogas mitigation from wastewater is that ex-ante emissions avoidance can be estimated entirely from default emissions factors and assumptions. Population estimates can be used if population data are not available. Centralized treatment plants discharge treated water in many ways, and information on these plants may be available if they report to an oversight body. Many wastewater treatment plants use the five-day biological oxygen demand (BOD_5) test to measure organics in untreated and treated wastewater. BOD_5 is also important for estimating biogas generation from anaerobic conditions or for calculating the effectiveness of a mitigation effort.

Wastewater treatment and discharge systems vary widely across regions and demographics. Some assumptions need to be made when estimating ex-ante biogas generation. An important consideration is estimating the fraction of the population that is urbanized compared to rural communities. Densely populated regions will likely have some form of centralized treatment for public health reasons, whereas rural regions are likely to have inexpensive forms of disposal (see Volume 5, Chapter 6 in the 2006 IPCC Guidelines, 2006e).

Key parameters for estimating biogas potential include:

- Type of wastewater treatment system
- Volume of wastewater received
- BOD/chemical oxygen demand (COD) measurements of incoming wastewater
- Total population served by the treatment system
- Annual per-capita protein consumption
- Fraction of wastewater from industry.

Several additional default factors are used in conjunction with the above list to estimate biogas production from wastewater.

Ex-Post Quantification of Emissions Reductions

Ex-post avoided emissions are calculated using BOD_5 or COD_5 tests of incoming and treated wastewater in conjunction with biogas sent to a destruction device(s). The BOD_5 test is a common measurement in municipal wastewater supplies, while the COD_5 test is a common measurement at industrial facilities that treat wastewater on site. To estimate avoided emissions, either the BOD_5 or COD_5 measurement of wastewater before and after a mitigation technology should be used. Subtracting the values and multiplying the result by the volume of wastewater treated will provide a rough estimate of avoided emissions. Uncombusted methane should also be accounted for.

Key parameters for measuring emissions reductions include:

- BOD/COD measurements of incoming wastewater
- Volume of incoming wastewater
- BOD/COD measurements of treated wastewater sent to effluent ponds
- Volume of treated wastewater sent to effluent ponds
- Any leaks from the biogas collection treatment system
- Flow meter measuring the total volume of biogas sent to a destruction device (e.g., flare, engine, boiler)
- Temperature and pressure readings of biogas (unless the flow meter internally corrects for these)
- Methane composition (either continuous, weekly, monthly, or quarterly measurements)
- Additional energy needed to support project activities
- Programmable logic controller that automatically records data points at specified intervals.

Appendix C. Biogas Emissions Quantification Tools and Resources

Exhibit C.1 provides information about several emissions quantification tools and resources for biogas sector projects.

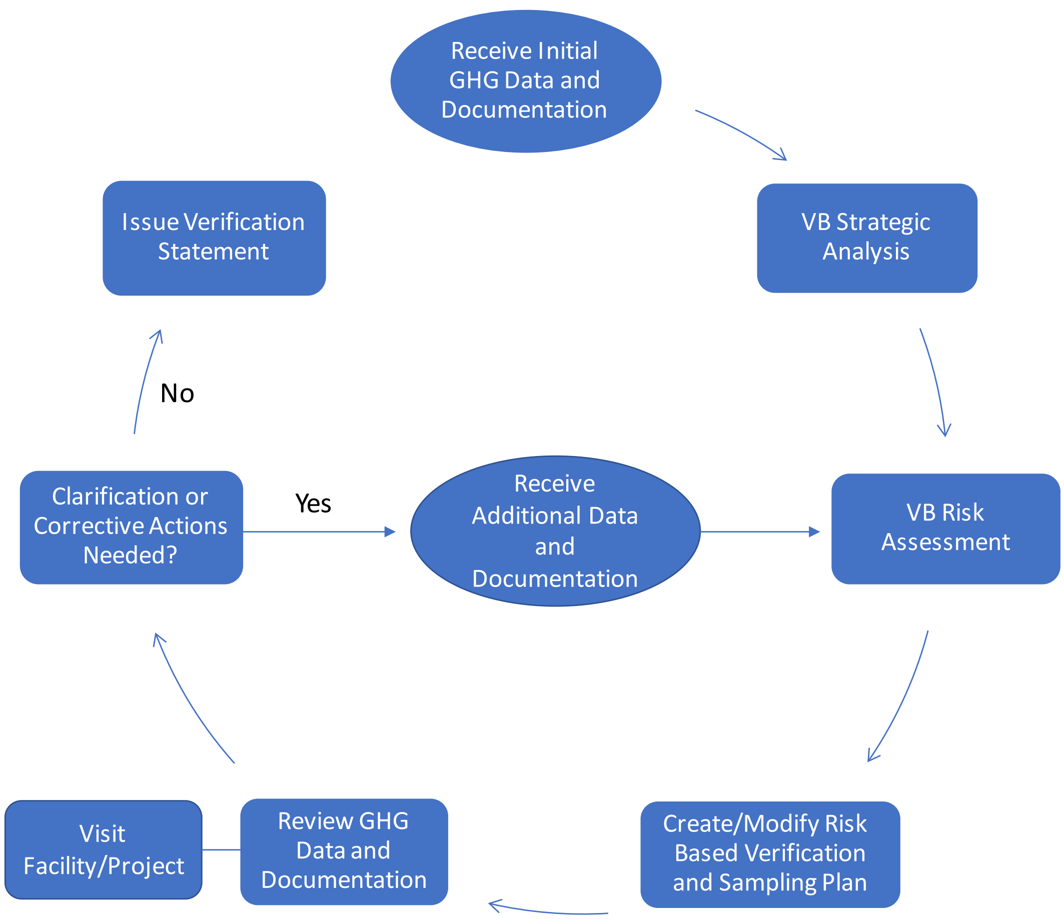
Exhibit C.1. Biogas Project Emissions Quantification Tools and Resources

Title	Developer	Description	Sector	Link
Solid Waste Emissions Estimation Tool (SWEET) Version 3.1	EPA	Downloadable MS Excel tool that estimates GHG emissions reductions for municipal solid waste projects. Helpful for city employees responsible for tracking climate impacts of waste activities.	Municipal solid waste	https://www.globalmethane.org/SWEET
Dairy Digester Research and Development Program (DDRDP) Benefits Calculator Tool	California Air Resources Board	Downloadable MS Excel tool to estimate greenhouse gas (GHG) emission reductions and selected co-benefits of each proposed project type for the DDRDP	Livestock Sector	https://www.arb.ca.gov/cc/capandtrade/auctionproceeds/cdfa_ddrdp_finalcalculatortool_2-3-20_v2.xlsx?_ga=2.217485142.1128183007.1623187107-1260972321.1614799065
Anaerobic Digestion Screening Tool	EPA	This tool allows users to perform rapid screening-level assessments of potential emissions reductions and biogas generation benefits of anaerobic digesters.	Municipal solid waste Agriculture Wastewater	https://www.globalmethane.org/resources/details.aspx?resourceid=5170
Landfill Gas Project Screening Tool	EPA	This simple MS Excel-based calculator estimates landfill gas emissions based on a limited number of data inputs.	Municipal solid waste	https://www.waste.ccacoalition.org/document/landfill-gas-project-screening-tool-version-2
Waste Reduction Model (WARM)	EPA	This downloadable software program calculates changes in GHG emissions from various waste management practices. Its intended users are solid waste planners and supporting organizations responsible for tracking and reporting GHG emissions.	Municipal solid waste	https://www.epa.gov/warm
IPCC Waste Model	IPCC	This spreadsheet tool calculates methane emissions from solid waste disposal, for use by individuals conducting the analysis.	Municipal solid waste	https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/IPCC_Waste_Model.xls
Climate Action Reserve Livestock Calculation Tool	Climate Action Reserve	This tool assists individuals conducting verification of GHG emissions reductions of livestock projects (U.S.-based projects only).	Agriculture	Available on request: http://www.climateactionreserve.org/how/protocols/us-livestock/
Biogas Wastewater Assessment Technology Tool (BioWATT)	EPA and the World Bank Group	This downloadable MS Excel tool calculates biogas production from waste-to-energy projects and the GHG emissions reductions from using biogas-generated electricity.	Wastewater	https://www.globalmethane.org/tools-resources/resource_details.aspx?r=1913

Appendix D. Verification Best Practices

Exhibit D.1 provides an illustration of the steps involved in the emissions reductions verification process, and Exhibit D.2 provides brief descriptions of each of these steps.

Exhibit D.1. Verification Process Illustration



VB = Verification Body

Exhibit D.2. Verification Process Activities

Verification Activity	Description
Receive initial GHG data and documentation	After initiating the verification, the project proponent or facility submits GHG data and documentation to the verification body, as required by the applicable program. This could include information on the baseline emissions scenario, measured data, equipment information, QA/QC documentation, or other supporting information.
Verification body strategic analysis	The verification body conducts an analysis of the project or facility regarding the criteria, scope, and complexity of the verification. The verification body also considers the project or facility's organization, management, and communication structure. The strategic analysis helps to inform the more detailed risk assessment.
Verification body risk assessment	The verification body identifies areas related to GHG emissions or other requirements of the applicable program that pose risk to reported GHG emissions or mitigations. The areas are reviewed for each type of risk (inherent, control, detection) and a discussion of why the risk exists is completed. All areas of risk must be addressed to complete the verification.
Create/modify risk-based verification plan and sampling plan	A verification plan and a sampling plan are developed based on the risk assessment and strategic analysis. The verification plan is standard across different projects and facilities. The sampling plan will vary from project to project based on specific requirements of the applicable program, as well as the risk associated with GHG data and documentation.
Review GHG data and documentation	The verification body reviews all provided GHG data and documentation and documents this review.
Visit facility/project	If required, the verification body will visit the project or facility to review GHG sources, measurement equipment, and data-recording equipment; and interview personnel.
Clarifications or corrective actions	The verification body will provide findings to the project or facility as a result of its review. Depending on the nature of the findings (material versus non-material), some errors will need to be corrected to complete the verification while others could potentially be ignored.
Receive additional data and documentation (if needed)	The project or facility will provide the verification body data and documentation to address the findings.
Risk assessment revision and sampling plan modification (if needed)	Based on the new data and documentation, the verification body will reassess the risk assessment and modify the sampling plan (e.g., one area of the data had errors, which led the verification body to increase sampling and re-review the area). This additional review could lead to novel findings.
Issue verification statement	Once all findings are closed out, the verification body will complete its verification process and issue a verification statement. The statement will note the criteria and scope of the verification, as well as the confirmed emissions value.