ANIMAL WASTE MANAGEMENT FOR

METHANE MITIGATION

LESSONS FROM BRAZIL FOR GLOBAL ACTION

Embrapa Swine & Poultry

i17

CLIMATE & CLEAN AIR COALITION TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

MINISTRY OF AGRICULTURE AND LIVESTOCK

BRAZILIAN GOVERNMENT BRASIL STANDING WITH THE BRAZILIAN PEOPLE

About this guide

This guide draws from Brazil's experience in reducing methane emissions in livestock and aims to help countries in the Global South develop national low-carbon strategies.

Technical coordination

Alessandro Sanches Pereira, i17

Deisi Cristina Tapparo, i17

Authors

Heloisa Campeão Rodrigues, i17

Gladis Maria Backes Bühring, i17

Larissa Boing, i17

Crislaine Florzino Flor, i17

Deisi Cristina Tapparo, i17

Alessandro Sanches Pereira, i17

Technical contributions

Instituto 17

Camila Ester Hollas, Daniela Candido, Guilherme Novaes Silva Pinto, Jessica Yuki de Lima Mito, Karina Guedes Cubas Amaral, Larissa Boing, Leidiane Ferronato Mariani, Liliane Klemann, Marcelo Henrique Manzke Brandt, Matheus Bueno Patrício, Renata Dahmer, Waleska de Gaspari Kronitzky, William Michelon.

Ministry of Agriculture and Livestock

Bruno dos Santos Alves Figueiredo Brasil, Kleber Villela Araújo, Larissa Arnhold Graminho, Marcio Ribeiro da Silva, Paulo Alexandre Meneses Mendes; Ricardo Kobal Raski, Rodrigo Moreira Dantas, Roberto Soares Rocha, Sidney Almeida Filgueira de Medeiros, Tiago Augusto da Silva.

Embrapa Swine and Poultry

Airton Kunz, Ana Claudia Lazaroto, Eliane Cristine Soares, Evandro Carlos Barros, Fabiane Goldschmidt Antes, Geordano Dalmedico, Martha Mayumi Higarashi, Ricardo Luis Radis Steinmetz.

Technical review

Airton Kunz, Embrapa Swine & Poultry.

Marina Bortoletti, Climate and Clean Air Coalition.

Raphael Esteves, Climate and Clean Air Coalition.

Ricardo Kobal Raski, Ministry of Agriculture and Livestock.

Sidney Almeida Filgueira de Medeiros, Ministry of Agriculture and Livestock.

Editorial coordination
Jessica Yuki de Lima Mito - Editorial coordination, i17.
Claudete Debértolis Ribeiro - Editorial review.
Marcelo Aramis - Graphic design and layout, Aramis Forma e Conteúdo.

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ANIMAL WASTE
MANAGEMENT FOR

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FOR GLOBAL ACTION

2025

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ACRONYMS

BC	Black Carbon
BEP	Brazil Energy Programme
BLC	Covered Lagoon Biodigester
CAPEX	Capital Expenditures
CCAC	Climate and Clean Air Coalition
CH_4	Methane
CNAE	National Classification of Economic Activities
C/N	Carbon/Nitrogen
CO_2	Carbon Dioxide
CSTR	Continuous Stirred-Tank Reactor
FAO	UN Food and Agriculture Organization
GHG	Greenhouse Gases
GESI	Gender Equality and Social Inclusion
GMI	Global Methane Initiative
HFCs	Hydrofluorocarbons
IBGE	Brazilian Institute of Geography and Statistics
IPCC	Intergovernmental Panel on Climate Change
K	Potassium
LCOB	Levelized Cost of Biogas
LCOE	Levelized Cost of Energy
LDC	Least Developed Countries
MCF	Methane Conversion Factor
N	Nitrogen
N_2O	Nitrous Oxide
O_3	Tropospheric Ozone
OECD	Organisation for Economic Co-operation and Development
OPEX	Operational Expenditures
P	Phosphorus
GWP	Global Warming Potential
SLCP	Short-Lived Climate Pollutant
MLS	Municipal Livestock Survey
RAIS	Annual Social Information Report
ROI	Return on Investment
SEEG	Greenhouse Gas Emissions Estimation System
SGAS	Swine Environmental Management System
IRR	Internal Rate of Return
MARR	Minimum Acceptable Rate of Return
NPV	Net Present Value

GLOSSARY OF UNITS AND SYMBOLS

%	Percent
°C	Degrees Celsius
gCH_4	Gram of Methane
kg	Kilogram
$kgCH_4$	Kilogram of Methane
kgVS	Kilogram of Volatile Solids
kt	Kilotonne
$ktCH_4$	Kilotonne of Methane
kWh	Kilowatt-hour
L	Liter
m^3	Cubic Meter
Mt	Megatonne
$MtCH_4$	Megatonne of Methane
MWh	Megawatt-hour
Nm^3	Normal Cubic Meter

FOREWORD

The National Policy on Climate Change (PNMC) of Brazil aims to balance the competitiveness of domestic economic sectors with efforts to reduce greenhouse gas emissions and boost resilience to climate impacts. The ABC Plan (2011–2020) and its successor, the ABC+ Plan (2020–2030), serve as sector-specific strategies to address climate change in Brazilian agriculture and livestock. These plans include proven production technologies designed for large-scale implementation, offering economic benefits to farmers while also reducing greenhouse gas (GHG) emissions. Among the key practices, animal waste management stands out for its ability to turn an environmental challenge into a source of renewable energy and biofertilizer.

The Climate and Clean Air Coalition (CCAC) has also highlighted the importance of methane (CH_4) mitigation as one of the most cost-effective methods to reduce global warming in the near term. In this context, the livestock sector presents both a challenge and an opportunity: to decrease emissions of a short-lived climate pollutant while also generating social, environmental, and economic co-benefits.

This guide was developed based on the Brazilian experience and aims to assist countries in creating national strategies for methane reduction in livestock. Its scope is global and adaptable: instead of providing a single solution, it offers key questions, methods, and examples that can be tailored to different productive, social, and institutional contexts. It serves as a practical resource for public managers, policymakers, technicians, researchers, and financial institutions interested in implementing scalable and inclusive solutions.

By combining science, practical experience, and public policy, this guide aims to assist other countries in developing more sustainable, productive, and resilient livestock systems. It encourages transforming diagnoses into concrete climate actions that support international commitments on sustainable development, a fair energy transition, and climate emergency.

Brazil offers this contribution as proof that combining food production, social inclusion, emissions reduction, and climate adaptation is achievable. We hope this material motivates governments and institutions worldwide to adopt more collaborative leadership in transitioning to low-carbon livestock and building a safer, fairer climate future for all.

Bruno dos Santos Alves Figueiredo Brasil
Director of Innovation, Sustainable Development and Irrigation
Ministry of Agriculture and Livestock – MAPA

PREFACE

Reducing methane emissions from livestock is one of the quickest and most cost-effective ways to address climate change. Besides cutting emissions of a short-lived climate pollutant, properly managing animal waste provides clear opportunities to generate renewable energy, replace chemical fertilizers, improve air quality, and boost food security. These advantages make it a crucial part of the climate agenda, especially for countries in the Global South, where livestock plays a vital role in the economy and the livelihoods of millions of families.

This recognition led to the development of this guide. Its purpose is to provide a practical and repeatable roadmap to assist governments, technicians, producers, and financial institutions in creating national strategies to reduce livestock methane emissions. Drawing from the Brazilian experience, the guide includes key questions, methods, and examples that help turn diagnoses into strong, scalable public policies. More than just a technical manual, it aims to transform knowledge into action by combining technological innovation, inclusive policies, and economic sustainability.

This work's goal is broad and flexible. The guide doesn't aim to provide a single solution but instead offers principles, steps, and tools that can be customized to each country's productive, social, and institutional context. Whether in intensive or extensive systems, family farms or large agribusinesses, the framework presented here can support both national programs and local initiatives for mitigation, always aiming to accelerate climate results, create economic co-benefits, and foster social inclusion.

The target audience of this guide is broad and strategic. It was created for policymakers, national and subnational managers, technicians from public and private organizations, researchers, extension agents, and civil society groups. It also addresses financial institutions and international cooperation agencies, which will find here criteria and examples to support scalable solutions aligned with global commitments such as the Paris Agreement, the Sustainable Development Goals, and the Global Methane Pledge. By combining science, practice, and experience, this guide seeks not only to provide guidance but also to inspire action. Its core message is clear: reducing methane emissions from livestock is a crucial opportunity for climate action that can benefit people, communities, and the environment.

1 INTRODUCTION

Livestock plays a vital role in global food security and supports developed and developing countries. Besides providing high-quality protein, the sector creates jobs, increases income, and stimulates local economies. With population growth and more rapid urbanization, the demand for food will stay high: global consumption of animal protein is expected to rise by about 21% by 2050 [1].

However, this expansion presents significant environmental challenges. Livestock is a major source of methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2), all of which are greenhouse gases (GHGs) that greatly impact the climate. Reducing non-CO_2 emissions has become a key part of global mitigation efforts. In this context, managing animal waste is a strategic approach: it allows for quick emission reductions, converts waste into biofertilizers and renewable energy, and offers direct social and economic benefits.

National experiences, like Brazil's, show that proper management of animal waste can turn an environmental problem into sources of clean energy, fertilizers, and social inclusion. Climate, energy, and related public policies must rely on accurate and reliable data. The following sections explain how to build this foundation for global, national, and regional assessments that support technical and policy decisions.

1.1 Objective of the guide

The goal of this guide is to help countries — especially those in the Global South — develop national strategies to reduce livestock methane emissions. Building on Brazil's experience, the document shows how to map value chains and production systems, select effective technologies, and turn analyses into tools that support policy design and implementation. Its goal is to offer a repeatable and adaptable approach, combining technical accuracy with clear language for public officials, technicians, producers, and policymakers.

This guide is intended for public managers, policymakers, and strategic actors. Its purpose is to:

- Organize key questions, reflections, and examples.
- Support understanding of animal production systems and waste generation.
- Present technical, institutional, and policy solutions available for waste management.

More than just compiling inventories, the guide is organized as a **practical roadmap,** inspired by the Brazilian experience and designed for adaptation by other countries in the Global South.

1.2 How to read and use this guide

This document should serve as a starting point for developing national and regional strategies for livestock waste management. By integrating data, technologies, policies, and examples from Brazil, it provides resources for each country to adapt solutions to their own circumstances, encouraging:

- Climate mitigation;
- Economic gains; and
- Social inclusion.

The guide was designed for various types of readers. You can use it as a comprehensive technical reference or as a convenient guide for quick implementation.

To improve clarity and applicability, the guide follows these conventions:

- **Bullet points (•)**
  Used to list actions, examples, or factors without a specific order. Example:
  - **Factors to consider;**
  - **Types of production systems;**
  - **Technology options.**

KEY MESSAGE

Summarize the main idea of each section in brief, clear sentences.

PRACTICAL EXAMPLE

Describe real or simulated experiences, primarily from Brazil's experience in livestock waste management. They show how methodological concepts can be used in practice but must always be tailored to each country's productive, climatic, and institutional conditions.

BOX

Used to expand on examples, case studies, social technologies, or international practices. They provide supporting material, including illustrative lessons that complement the main text, and always include a brief key message.

MAIN TAKEAWAY

Highlights key lessons and insights that can be replicated in other contexts

- **Numbered lists (1, 2, 3...)**

Used to show steps or recommendations in a logical order (e.g., steps to perform a diagnosis, phases to implement a technology).

1. **Documentary research**
2. **Technical analysis with experts**
3. **Consultation with key sector stakeholders**

Lessons for replication

1. Keep in mind: highlight methodological principles and universal recommendations that can be applied across various contexts, serving as adaptable references.

Checklist for Chapter 1

☐	**Read the introduction**	Offers a strategic overview of how the guide aids climate planning and integrated policy development.
☐	**Use the key messages**	Summarizes the main insights of each chapter, making it easier to apply them in decision-making.
☐	**Use practical checklists**	Checklists to translate technical recommendations into specific, measurable management actions.
☐	**Refer to Tables, Figures, and Boxes**	Provides data and case examples that support evidence-based decisions.
☐	**Adapt brazilian lessons**	Expands solution replicability by aligning them with local governance structures and policy tools.

2 GLOBAL LIVESTOCK EMISSIONS AND THE ROLE OF WASTE MANAGEMENT

Building on the framework established in Chapter 1, the next step is to examine the overall picture of livestock emissions, which provides the foundation for national assessments and solution development.

This guide serves as a map, and each country must chart its own course by tailoring solutions to its productive, climatic, and institutional realities. Chapter 2 emphasizes the importance of waste management as a cost-effective methane reduction strategy and explains how to use this guide. This initial framing connects the Brazilian experience to the global emissions landscape, which is discussed in Chapter 3.

Greenhouse gas (GHG) emissions from livestock come from various sources, both **direct** and **indirect**.

- **Direct:** generated within the production unit itself, such as enteric fermentation (CH_4 produced during ruminant digestion) and animal waste management (CH_4 and N_2O emissions during storage, treatment, and application of residues).
- **Indirect:** related to supporting activities like land-use change for pasture and input use, as well as producing and transporting feed and supplements.

For **methane**, enteric fermentation and waste management together account for about one-third of global emissions [2]. Although waste management contributes a smaller share — approximately 7.8% of livestock emissions — its mitigation is strategic because it provides:

- **Quick and measurable results:** CH_4 control produces instant impacts on the global warming trend.
- **Availability of proven technologies:** biodigesters, composting, and good practices are already in use, reducing emissions and helping control soil and water pollution.
- **Relatively low cost:** mitigation measures are more affordable and easier to access than alternatives in other sectors.

2.1 Why is methane a priority?

Among greenhouse gases, CH_4 deserves special attention for three reasons [3]:

- **Global Warming Potential (GWP):** approximately 28 times higher than carbon dioxide (CO_2) over 100 years and 86 times higher over 20 years.
- **Short atmospheric lifetime:** about 12 years, meaning reducing emissions now offers nearly immediate climate benefits.
- **Classification:** a short-lived climate pollutant (SLCP).

This makes CH_4 both a challenge and an opportunity for rapid reduction:

- Slows global warming over 10–20 years.
- Helps prevent climate tipping points[1];
- Generates immediate benefits for public health, air quality, and food security.

[1] Contributes to preventing the climate from reaching critical tipping points.

KEY MESSAGE

Addressing CH_4 is strategic because it offers immediate climate benefits along with health, air quality, and food security advantages. This focus informs the technical and policy solutions described in the following chapters.

BOX 1 SHORT-LIVED CLIMATE POLLUTANTS (SLCPs)

Short-lived climate pollutants (SLCPs) remain in the atmosphere for periods ranging from days to a few decades, but they have a high global warming potential. Key examples include:

- *Methane (CH_4) — atmospheric lifetime of about 12 years; emitted from livestock manure management, intensive animal production systems, landfills, and natural gas production and leakage.*
- *Black Carbon (BC) — remains in the atmosphere for a few days to weeks; produced by incomplete combustion of biomass, agricultural burning, diesel engines, and poorly operated stoves and kilns.*
- *Tropospheric Ozone (O_3) — atmospheric lifetime of hours to weeks; not emitted directly but formed through chemical reactions involving methane (CH_4), nitrogen oxides (NO_2), and volatile organic compounds (VOCs).*
- *Hydrofluorocarbons (HFCs) — atmospheric lifetime ranging from a few years up to about 15 years (depending on the compound); used in refrigeration, air conditioning, foams, aerosols, and industrial solvents.*

Although less persistent than CO_2, SLCPs have high radiative efficiency, meaning they trap much more heat per unit of mass [4]. Their mitigation is strategic to:

- ***Gain time** in addressing climate emergencies, avoiding critical thresholds.*
- ***Reduce local impacts,** such as air pollution and respiratory problems.*
- ***Strengthen food system resilience**, as air pollution reduces agricultural productivity.*

In the agricultural sector, CH_4 is the most relevant SLCP, accounting for about 32% of global anthropogenic emissions.

MAIN TAKEAWAY

Reducing SLCPs does not replace long-term decarbonization, but it remains one of the most effective ways to keep global warming within 1.5°C by 2030, as set out in the Paris Agreement. This vision complements the analysis on how to integrate short- and medium-term solutions into national strategies.

2.2 Evolution and distribution of emissions

Over the past thirty years, livestock emissions have steadily risen, mirroring the increase in animal protein consumption. From **1990** to **2018**, **CH_4** emissions from **enteric fermentation** and animal **waste management** grew by approximately **15%** [5].

Although the energy sector still accounts for the largest share of global GHG emissions, livestock's contribution is particularly significant because of CH_4's impact. According to the Global Methane Assessment, reducing this gas is one of the quickest and most cost-effective ways to cut global warming and prevent irreversible tipping points [2].

In 2022, global emissions from waste management totaled about **9.94 $MtCH_4$** , with projections indicating an increase to **11.15 $MtCH_4$**[2] by 2050 if effective mitigation measures are not taken [6].

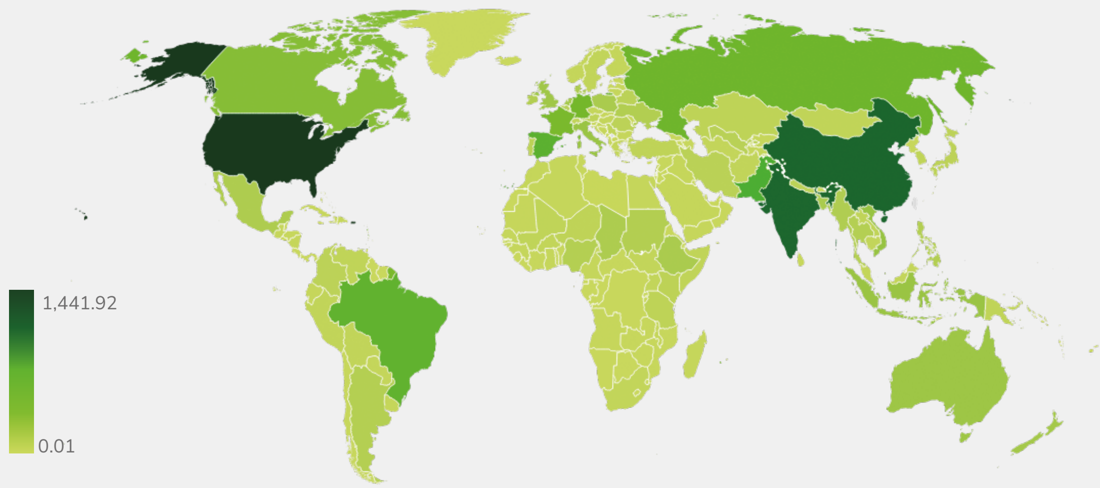
2.2.1 Regional and species differences

Emissions from waste management happen in all production systems, including ruminant and monogastric systems, but their level and distribution vary greatly around the world.

Figure 1 shows the global distribution as of 2022. The highest emissions are in **North America**, **South Asia**, and **East Asia**, where intensive animal production systems are common. This concentration relates to high animal densities in confined areas, the widespread use of industrial value chains (especially swine and dairy cattle), and the heavy use of inputs, all of which boost the amount and concentration of animal waste. This regional focus not only points out the areas with the biggest climate impact but also highlights the most strategic locations for deploying mitigation technologies.

[2] $MtCH_4$ is the unit representing megatonnes of methane, equivalent to 1 million tonnes of CH_4 emitted. $ktCH_4$ represents kilotonnes of methane, corresponding to 1 thousand tonnes of CH_4 emitted.

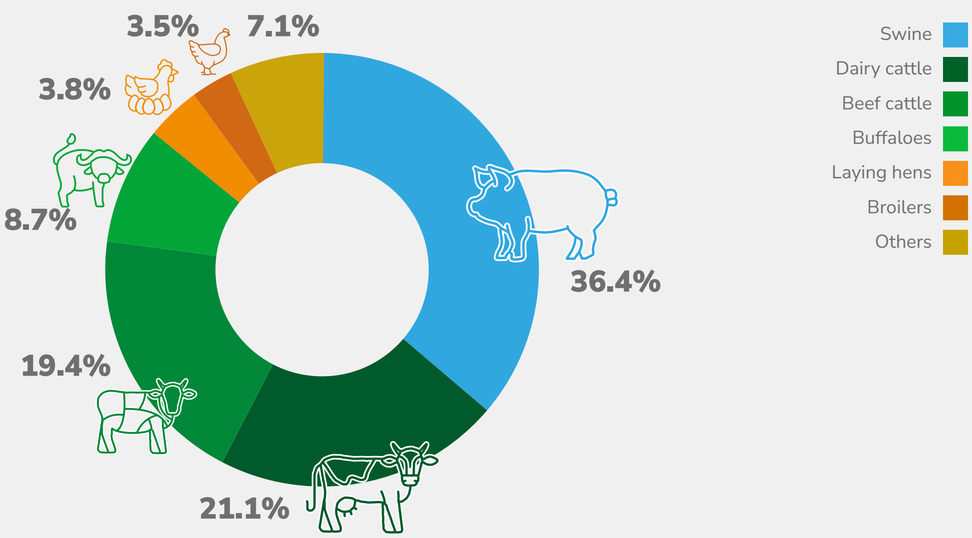
Figure 1. **Global distribution of methane emissions from animal waste in 2022 ($ktCH_4$)**



Source: prepared using FAOSTAT data [6].

Variations are also evident among animal species. As shown in Figure 2, swine accounts for the largest share of global emissions, followed by dairy cattle, beef cattle, buffalo, laying hens, and broilers. This reflects not only herd size but also the distinct characteristics of the waste and management practices used in each chain.

Figure 2. **Share of animal categories in methane emissions from waste management in 2022**

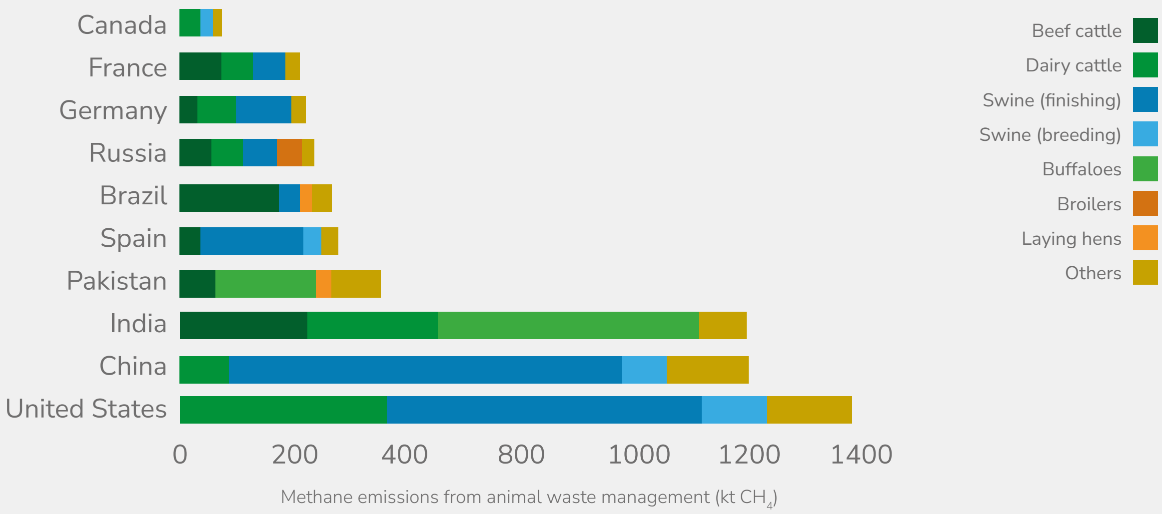


Source: prepared using FAOSTAT data [6].

Analyzing this distribution by country income group shows that **high-income countries account for 50.7% of global waste** management emissions, followed by upper-middle-income (23.4%), lower-middle-income (21.5%), and low-income countries (4.4%). These differences relate to both production levels and herd scale.

Differences among countries are even more noticeable in Figure 3, which displays the ten largest emitters in 2022: the **United States, China, India, Pakistan, Spain, Brazil, Russia, Germany, France**, and **Canada**.

Figure 3. **Ranking of the top 10 countries with the highest methane emissions and their respective livestock categories in 2022 (kt CH_4)**



Source: prepared using FAOSTAT data [6].

These figures indicate that intensive livestock — particularly **swine** and **dairy cattle** — have the highest emission levels. At the same time, these systems also offer **the best conditions for implementing mitigation technologies**, since the concentration of animals makes waste collection, storage, and treatment more manageable.

These regional differences demonstrate that emission patterns vary by location, species, and income level, serving as a comparative reference among countries. In the Global South, where detailed statistics may be limited, international databases such as FAO[3] and IPCC[4] provide common parameters that enable initial comparability. These values should be used as a starting point and gradually refined as national or local data becomes available.

[3] Food and Agriculture Organization of the United Nations (FAO) is the UN agency responsible for collecting global data on agriculture, livestock, forestry, fisheries, and food security. It publishes the FAOSTAT database, one of the world's main international sources of information on livestock, production, and emissions, widely used by countries as a methodological reference.

[4] Intergovernmental Panel on Climate Change (IPCC) is the UN scientific body responsible for assessing evidence on climate change and providing methodological guidance for the preparation of national greenhouse gas inventories.

KEY MESSAGE

Mapping regions, species, and countries with the highest contributions helps allocate mitigation resources more effectively. These data serve as the baseline for setting priorities, discussed in the next chapter.

2.3 Implications for Global Action

The global overview of emissions from animal waste management shows that, despite variations across regions and species, this is an issue that impacts all production systems. By highlighting the scope of the challenge, it also reveals mitigation opportunities that can be quickly implemented and provide multiple co-benefits. To convert diagnoses into unified national strategies, four essential steps are necessary:

1. **Identify available data sources**
   - National agricultural censuses.
   - National inventories of GHG emissions.
   - International databases (FAO, IPCC, CCAC, GMI - Global Methane Initiative).
   - Regional or subnational monitoring systems.
2. **Locate priority value chains and species**
   - Map which animal categories concentrate on the largest volume of waste and emissions (e.g., swine, dairy cattle, poultry).
   - Verify the geographic concentration of production hubs.
3. **Cross-check information on volume, density, and production practices**
   - Intensive systems emphasize animal waste management technologies such as biodigesters and composting.
   - Extensive systems focus on proper soil management, conservation practices, pasture management, and indirect incentives.
4. **Project the energy potential of animal waste**
   - Calculate the mitigation potential of priority regions.
   - Translate waste volumes into energy equivalents (biogas, biomethane, electricity).

KEY MESSAGE

Managing animal waste should be a priority and a cost-effective way to reduce CH_4, able to produce quick climate benefits and additional co-benefits. This global overview sets the baseline for mapping production systems and identifying national priorities, as discussed in Chapter 3.

Checklist for Chapter 2

☐	**Analyze the global distribution of emissions**	Clarifies the country's position relative to major sources worldwide and identify key sectors for mitigation.
☐	**Use reliable international databases (FAO, IPCC, and others)**	Aligns national policies with recognized methodologies, enhancing comparability and transparency internationally.
☐	**Identify global patterns of risk and opportunity**	Forecasts global shifts that impact investment priorities and partnership chances.
☐	**Translate global numbers into national implications**	Support the definition of realistic targets and strategies aligned with national potential and production conditions, as detailed in Chapter 3.

3 MAPPING ANIMAL PRODUCTION SYSTEMS AND IDENTIFYING PRIORITIES

After establishing the global diagnosis in Chapter 2, the next step is to adapt this baseline to the national level by defining specific strategies through mapping value chains, production systems, and waste volumes. This process helps identify mitigation priorities.

Setting **mitigation targets**, **selecting technologies**, and **developing monitoring mechanisms** can only be effective when based on a thorough understanding of the **country's production landscape**. This initial step ensures policies are **tailored to the local context**, increasing their effectiveness.

Furthermore, a comprehensive understanding of production systems allows for the development of solutions that are **technically appropriate, economically viable**, and **socially significant all at once.**

This chapter provides **guiding principles** to help decision-making in developing mitigation strategies for the livestock sector. It presents the **Brazilian experience** as an example, illustrating how these strategies can be adapted and applied to other productive settings, particularly in the Global South.

Mapping animal production systems is, therefore, the first step in any mitigation plan. This process addresses three key questions:

- **Which value chains and species are priorities?**
- **Which production systems predominate?**
- **How, where, and at what volume is animal waste generated and managed?**

The Brazilian experience demonstrates that **integrating agricultural censuses, emission inventories, and territorial data** offers a practical, comparable, and valuable perspective for policymaking. Other countries can adopt a similar approach, tailoring their **priorities** based on local productivity, climate, and institutional conditions.

KEY MESSAGE

Mapping production systems is essential for identifying where the highest waste volumes occur and, consequently, where the greatest opportunities for mitigation are. This step connects the global diagnosis in Chapter 2 with the development of national priorities that guide the selection of technologies and policies in the following chapters.

3.1 Which value chains are most representative in the country?

Identifying the key value chains is the initial step in any livestock mitigation plan. Before selecting technologies or establishing monitoring systems, it is crucial to understand:

- Which animal species generate the most waste and CH_4 emissions;
- Where the primary production hubs are located and the size of the herds; and
- The socioeconomic importance of these activities.

This initial diagnosis is key because resources for mitigation are limited. Directing them toward high-impact chains ensures **effective use of funds and builds trust with both national and international financiers.**

PRACTICAL EXAMPLE

This prioritization revealed a wide range of systems across Brazil, reflecting the country's large size, diverse biomes, and different levels of intensification. Despite this diversity, three value chains stand out as strategic.

- **Swine farming in southern Brazil features :** high production density, primarily generating liquid waste with a high organic load. This creates environmental risks but also significant opportunities for biodigesters, bioenergy, and biofertilizer programs.
- **Cattle farming:** herds are mainly located in the Center-West, which has the largest herds in the world. Extensive systems are common, making waste collection and treatment difficult. Still, owning feedlot hubs creates good conditions for adopting technological solutions.
- **Poultry farming** is found in many regions, especially in the South and Southeast, and mainly involves high-density industrial systems. It generates solid waste that can be used for composting and as organic fertilizer.

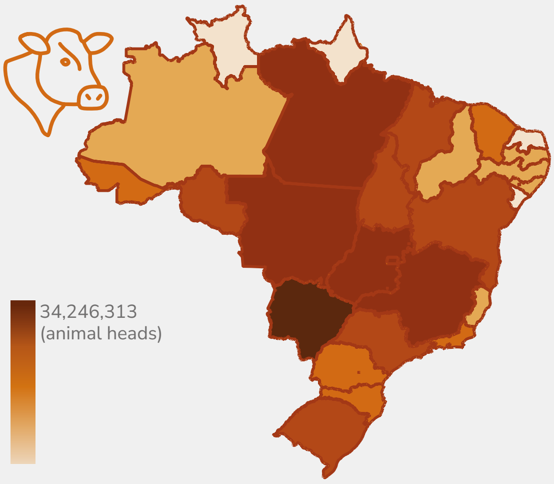
The database supporting this mapping in Brazil is extensive and diverse. The Brazilian Institute of Geography and Statistics (IBGE) provides agricultural censuses and the Municipal Livestock Survey (MLS), which detail herds by animal category. These are complemented by estimates from the National Greenhouse Gas Inventory and by independent systems such as the Greenhouse Gas Emissions and Removals Estimating System (SEEG)[5], which offer consistent and current data on sectoral emissions. Combining these sources enables the identification of production hubs and the quantification of mitigation potential by value chain and region.

[5] SEEG is an independent Brazilian initiative that provides annual estimates of GHG emissions and removals across sectors, complementing the official National Inventory and widely used by policymakers, researchers, and civil society. https://seeg.eco.br/english/home/

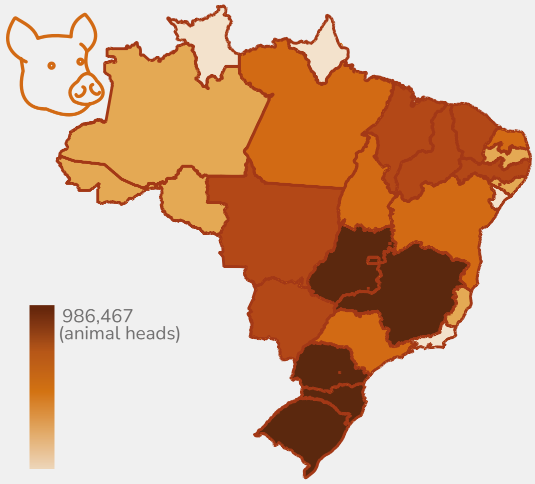
The spatial distribution of these data (Figure 4) clearly indicates that swine production is in the South, cattle in the Center-West, and poultry[6] in the South and Southeast.

Figure 4. **Distribution of livestock chains in Brazil**

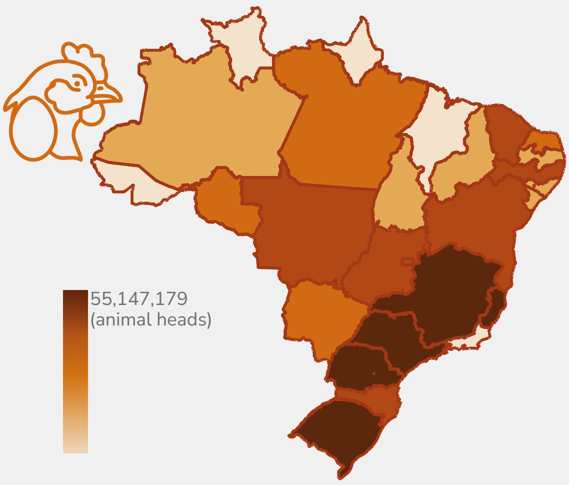
a) cattle herd (beef and dairy);



b) swine herd (reproduction and finishing);



c) Laying hen herd
(estimated from egg production,
assuming 0.9 eggs per hen per day)



Source: prepared using data of [7], [8] and [9]

Even in countries without comprehensive agricultural censuses or detailed inventories, it remains possible to implement the same approach, starting with available data and supplemented by international statistics (FAO, IPCC, CCAC, GMI) or sample surveys. **The key is to combine different sources** — official, academic, and sectoral — and to verify herd, production, and emission data to establish national priorities.

[4] Layer poultry production systems.

BOX 2 — SGAS IN BRAZIL: STANDARDIZING DATA FOR ENVIRONMENTAL MANAGEMENT IN SWINE FARMING

*The **Swine Environmental Management System (SGAS)** is software developed by Embrapa Swine and Poultry, in partnership with public and private institutions, to support the management and environmental licensing of swine farms.*

It integrates zootechnical, environmental, and management variables in a single platform, allowing producers and managers to have a detailed view of the production system.

What SGAS does:

- *Collects data on a number of animals, production stage (full cycle, finishing, maternity, etc.), water consumption, and volume of effluents generated.*
- *Provides technical support to design waste treatment systems (ponds, biodigesters, composting).*
- *Allows individual farm planning and evidence-based public policy design.*

***Target audience:** rural producers, extension technicians, agroindustry managers, cooperatives, environmental agency analysts, and policymakers.*

International replication potential:

- *Flexible platform, adaptable to different environmental legislation.*
- *Promotes **data standardization** and improves traceability.*
- *Facilitates access to **green credit and climate incentive programs**, expanding financing opportunities for producers and governments.*

MAIN TAKEAWAY

Simple digital systems, such as SGAS, transform scattered data into concrete public policies. Any country can develop similar platforms, adjusting variables to its productive and regulatory reality.

KEY MESSAGE

Focusing on strategic value chains directs efforts to where climate and socioeconomic impacts are greatest. This prioritization forms the basis for analyzing production systems and selecting technical solutions suited to each context.

Lessons for replication

1. Begin with strategic value chains: identify which animal species generate the most waste and emissions. This ensures focus on the most impactful sectors.

2. Consider productive and socioeconomic realities: mapping must account for both herd size and the economic and regional importance of each chain.

3. Rely on integrated databases:

a. National agricultural censuses.
b. GHG emission inventories.
c. International databases (FAO, IPCC, CCAC, GMI).
d. Regional or subnational monitoring systems.

4. Define national mitigation priorities: identify key production centers and establish clear prioritization criteria, such as emission reduction, energy generation, or fertilizer production. This directs more efficient resource allocation.

5. Keep decision-making focused: the main goal is to clearly show where mitigation efforts will provide the greatest environmental and economic benefits.

3.2 Which production systems are predominant?

Once the priority value chains are identified, the next step is to understand how the animals are raised, because the system type directly influences the amount and composition of waste produced.

Characterizing animal production systems is essential for developing mitigation strategies. How animals are raised influences not only **productivity** but also the **quantity**, type, and **concentration of waste** generated. These elements, in turn, directly impact the **technical**, **economic**, and **environmental feasibility** of waste management and treatment solutions.

Two main criteria help organize this classification:

- **Socioeconomic criterion:** distinguishes subsistence systems (focused on self-consumption), small-scale systems (diversified, supporting family income), and commercial or industrial systems (large-scale production linked to structured value chains).
- **Intensification criterion:** ranges from extensive systems (low density on natural or cultivated pastures) to semi-intensive systems (pasture with supplementary feed), and up to intensive systems (high-density confinement with balanced diets).

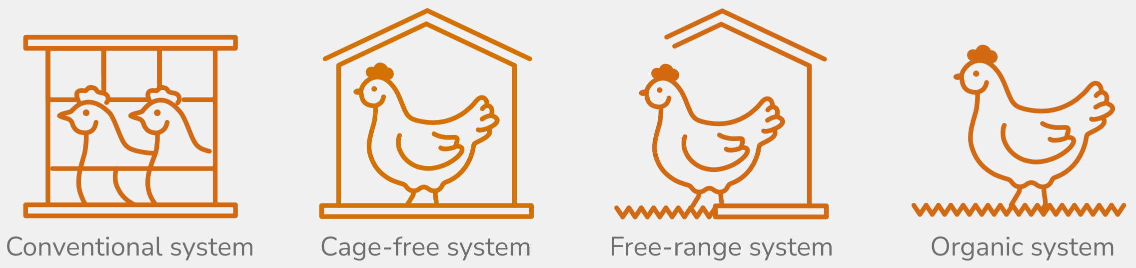
In **extensive systems**, common in cattle farming in tropical countries, animals are kept on large pasture areas. Waste is dispersed, reducing the risk of local pollution but making collection and energy use more difficult. **Semi-intensive** systems combine pasture-based raising with feed supplementation, serving as a transition between productivity and sustainability. Finally, **intensive systems**, typical of swine and industrial poultry farming, concentrate many animals in small areas, producing large amounts of liquid or solid waste with high pollution potential, while also making technological treatment more feasible.

3.2.1 Examples of more technologically advanced systems

As systems become more complex, the connection between management and emissions becomes even clearer.

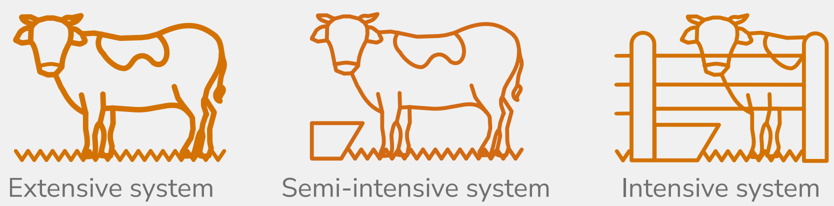
Laying hen production: In Brazil, laying hen production mainly occurs in conventional high-density systems with automated feeding, egg collection, and waste removal. This approach ensures high productivity and lower costs but produces large amounts of solid waste. Recently, alternative systems such as cage-free, free-range, and organic have become more popular, driven by increased demand for animal welfare. These models generate waste with different characteristics and require more complex management strategies (Figure 5).

Figure 5. **Production systems in laying hen farming**



Beef cattle farming: traditionally based on extensive systems, Brazilian beef cattle farming is shifting toward intensification. The growth of feedlots and semi-feedlots concentrates waste in smaller areas, enabling the use of treatment technologies (Figure 6). This change opens the door for solutions like biodigesters, which were previously impractical in fully pasture-based systems.

Figure 6. **Production systems in beef cattle farming**



Dairy cattle farming: primarily relies on extensive and semi-intensive systems, but there is significant growth in intensive systems such as free stall and compost barn (Figure 7). This transition enhances productivity and animal welfare while also helping to decrease emissions through improved waste management.

Figure 7. **Intensive production systems in dairy cattle farming**

BOX 3 DOES THE COMPOST BARN REDUCE GHG EMISSIONS?

The compost barn is an intensive confinement system increasingly adopted in Brazilian dairy cattle farming. In it, animals remain loose in covered barns on a deep bedding of wood shavings, sawdust, or other absorbent material. In addition to promoting animal welfare, thermal comfort, and easier management, the compost barn allows waste decomposition to occur predominantly under aerobic conditions, significantly reducing methane (CH_4) and nitrous oxide (N_2O) emissions.

Starting diagnosis

Studies show that the Methane Conversion Factor (MCF) of this system is only 1.5%, far below the values observed in anaerobic lagoons or manure deep pits, which can exceed 80% in tropical regions [10]. When properly managed, with frequent bedding aeration and moisture control, compost barns present emission levels similar to windrow composting, with the added advantage of combining animal comfort and reduced costs for waste transport and storage.

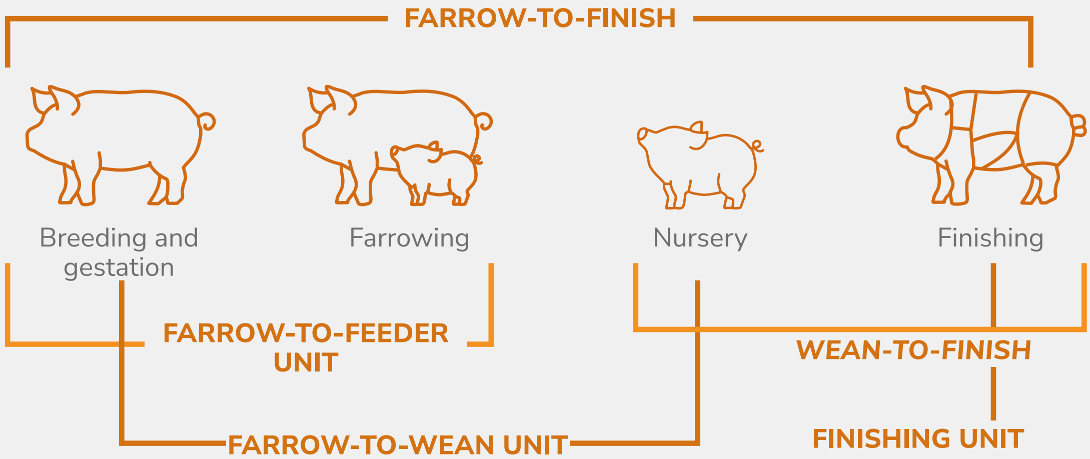
However, effectiveness depends on management: lack of aeration and moisture buildup can reverse the environmental gains. Brazilian experiences have shown consistent reductions in CH_4 emissions after proper bedding aeration [11].

MAIN TAKEAWAY

The compost barn is a solution that combines productivity, animal welfare, and emissions mitigation. Countries seeking to intensify dairy production sustainably can replicate this model, provided they invest in training and efficient management.

Intensive swine farming: Intensive swine farming in Brazil can be organized into various production models. One of this models is the farrow-to-finish, where all stages—breeding and gestation, farrowing, nursery, and finishing—occur within a single unit, concentrating significant amounts of waste in one location. Specialized systems, such as farrow-to-feeder, farrow-to-wean and finishing units, divide the process into stages, enabling greater zootechnical efficiency but also resulting in different waste generation profiles (Figure 8). All of these generate large amounts of liquid waste. Although this setup is complex, it provides the best conditions for using biodigesters and composting.

Figure 8. **Intensive production systems in swine farming**



These organizational arrangements directly affect the amount, composition, and frequency of waste, which are crucial factors in determining the size of treatment technologies like biodigesters, anaerobic lagoons, or composting facilities.

KEY MESSAGE

The amount and makeup of waste are directly connected to the production system, which influences the practicality of management and mitigation solutions for each case. Analyzing these systems helps determine where and how much waste is produced.

Lessons for replication

1. Characterize production systems: understanding how animals are raised is essential for developing realistic and effective mitigation strategies.

2. Adapt solutions to the system:
a. Extensive systems require careful management of pasture, fire prevention, and soil practices.
b. Intensive systems are more practical for technologies like biodigesters and composting.

3. Recognize chain-specific aspects: understanding the unique features of each animal category and the shift from extensive to intensive systems helps plan short-, medium-, and long-term actions.

4. Balance mitigation and productivity: tailored policies by system type increase adoption and make low-carbon livestock more practical in different settings.

5. Remember: there is no one-size-fits-all solution. Strategies must be customized based on producers' socioeconomic profiles and their level of intensification.

3.3 How is waste generated in intensive systems?

The rise in animal production — whether in pigs, poultry, or confined cattle — focuses many animals into smaller areas. This arrangement results in the buildup of large **amounts of waste**, usually in liquid or semi-liquid form, mixed with cleaning water, feed leftovers, and urine.

In extensive systems, waste remains dispersed in the soil and is reabsorbed into the local ecosystem. In intensive systems, accumulated waste can become a **direct environmental problem**, requiring specific strategies for:

- collection,
- storage,
- treatment, and
- whenever possible, energetic, and agronomic use.

3.3.1 Key technical aspects

- The characteristics of waste, how often it is removed, and the type of collection influence the effectiveness of different technologies.
- Systems that store liquid waste in lagoons promote CH_4 production under anaerobic conditions.
- Systems with solid waste generally emit less CH_4 and are more suitable for composting.

Another important aspect is **measuring waste volume**. Average reference values are useful but need to be adjusted for the local context, including **diet, animal genetics, production system,** and **climate**. Relying only on average values can lead to errors in sizing technologies or estimating emissions.

3.3.2 Animal waste generation in Brazil varies

Table 1 summarizes the waste generation ranges for different animal categories in the Brazilian context. These figures can be used as a starting point for other countries, as long as they are adjusted with local data.

Table 1. **Animal waste generation ranges by animal category in Brazilian livestock**

Production system		Volume (L/animal/day)
Dairy cattle		21[a]-136[b]
Beef cattle		21[a]-80[c]
Swine	Nursery	1.4[d]-2.76[e]
	Breeding	16[e,f]
	Boar	6.5[g]-9.0[d]
	Farrow-to-feeder unit	11.4[g]-22.8[h]
	Farrow-to-wean unit	1.6[g]-27[f]
	Finishing Unit	4.5[f]-8.33[e]
	Farrow-to-finish unit	47.1[f]-50.6[g]
Laying hens	Automated systems*	0.1[i]
	Conventional systems*	0.05[i]
	2.5 kg hens*	0.12[j]-0.18[j]

*kg/animal/day
a[12]; b[13]; c[14]; d[14]; e[16]; f[17]; g[18]; h[15]; i[16]; j[17].

3.3.3 Differences in production systems

- **Intensive swine farming:** produces liquid waste rich in organic material, nitrogen, and phosphorus, making it suitable for anaerobic biodigestion.
- **Laying hen production:** solid waste, feathers, feed residues, and bedding material are more appropriate for composting or co-digestion with other residues.
- **Confined cattle farming:** liquid or semi-liquid mixture; potential for biodigestion, but depends on scale and infrastructure.

This distinction explains why swine farming is better suited for biodigestion, while poultry farming has greater potential for composting.

KEY MESSAGE

Mapping the generation, location, and volume of livestock waste helps identify hotspots with greater impact and estimates the energy potential for biogas and biofertilizers. This information provides the basis for selecting appropriate management technologies.

Lessons for replication

1. Use average values only as a starting point: they assist with the initial sizing of technologies but need to be refined with local data on diet, animal genetics, climate, and production system.

2. Differentiate between liquid and solid waste: this distinction is key to determining management and treatment options such as biodigestion, composting, stabilization lagoons, or co-digestion.

3. Integrate zootechnical and environmental data: combine herd information, emission inventories, and scientific research results to generate more precise and dependable estimates.

4. Prioritize scalable solutions: focus efforts on chains and regions where waste volume justifies policies for mitigation and investments in bioenergy and biofertilizers.

3.4 Which technologies are available or feasible?

The characterization of waste helps assess available technologies. Waste management in intensive systems relies on p**roduction scale and infrastructure**. Centralized waste collection, typical in these systems, offers both opportunities and challenges.

- **Oportunity:** supports mitigation technologies like anaerobic biodigestion and composting, which reduce emissions and generate valuable by-products.
- **Challenge:** requires clear regulations, access to funding, and technological adaptation to the local environment.

PRACTICAL EXAMPLE

In Brazilian swine farms, studies show that replacing **open lagoons** with **biodigesters** reduces greenhouse gas emissions (in CO_2eq) by **74%** to **106%** , while also producing **biogas** for electricity and digestate as a **biofertilizer for agriculture**[7] [18]. Besides the climate benefit, this measure offers co-benefits such as odor reduction and increased social acceptance of intensive production.

Before proposing new technologies, it is important to first conduct a baseline assessment of how waste is generated, collected, stored, and treated. This mapping helps identify which practices are already well-established and the main sources of CH_4 and N_2O emissions. This initial assessment prevents solutions that are disconnected from reality and supports the development of gradual transitions, building on routines already in place in the sector.

In Brazil, for example, the National Emissions Inventory serves as the main tool for understanding how management systems are spread across different value chains [19]. In 2020, it was found that:

- **In high-production dairy cattle farming,** 82% of waste remains on pasture, 18% is managed in anaerobic lagoons, and only a small portion goes through biodigesters.
- **In swine farming**, storage **lagoons without added wate**r (slurry systems) were the most common, followed by biodigesters.
- **In laying hen farming**, the most common system uses **cages with floor deposition** and **regular waste removal.**

[7] Results from studies conducted in five swine production units compared methane emissions from manure storage systems (open lagoons) and treatment systems (biodigesters) operating at different scales and under varying conditions in the states of Paraná and Minas Gerais.

This type of survey can be repeated in any country. National inventories, agricultural censuses, producer associations, and academic research offer the basis for describing common practices. At the global level, databases like those from FAO and multilateral initiatives (e.g., CCAC, GMI) provide comparable methodological standards.

Technologies and their related emissions

The CH_4 emissions are directly affected by management practices.

- **Liquid systems** (lagoons, tanks, deep pits) facilitate anaerobic decomposition and produce significant quantities of methane.
- **Solid systems** (windrows, dry lots, direct application on soil) break down more effectively in aerobic conditions, resulting in significantly lower emissions.

Table 2 displays the Methane Conversion Factors (MCF) for different animal species and climate conditions, based on the IPCC [20]. These factors show **the amount of CH_4** emitted per kilogram of **volatile solids (VS)** in waste ($gCH_4/kgVS$), allowing comparison of the emission levels across various management methods.

The data shows that **liquid and open systems**, like anaerobic lagoons, are the main emitters — especially in tropical climates — while more controlled systems such as **biodigesters** and **composting** have much lower emission rates. In practice, replacing open lagoons with biodigesters can cut emissions by ten times or more, and composting can reduce **emissions by up to 30%** compared to manure deep pits [21].

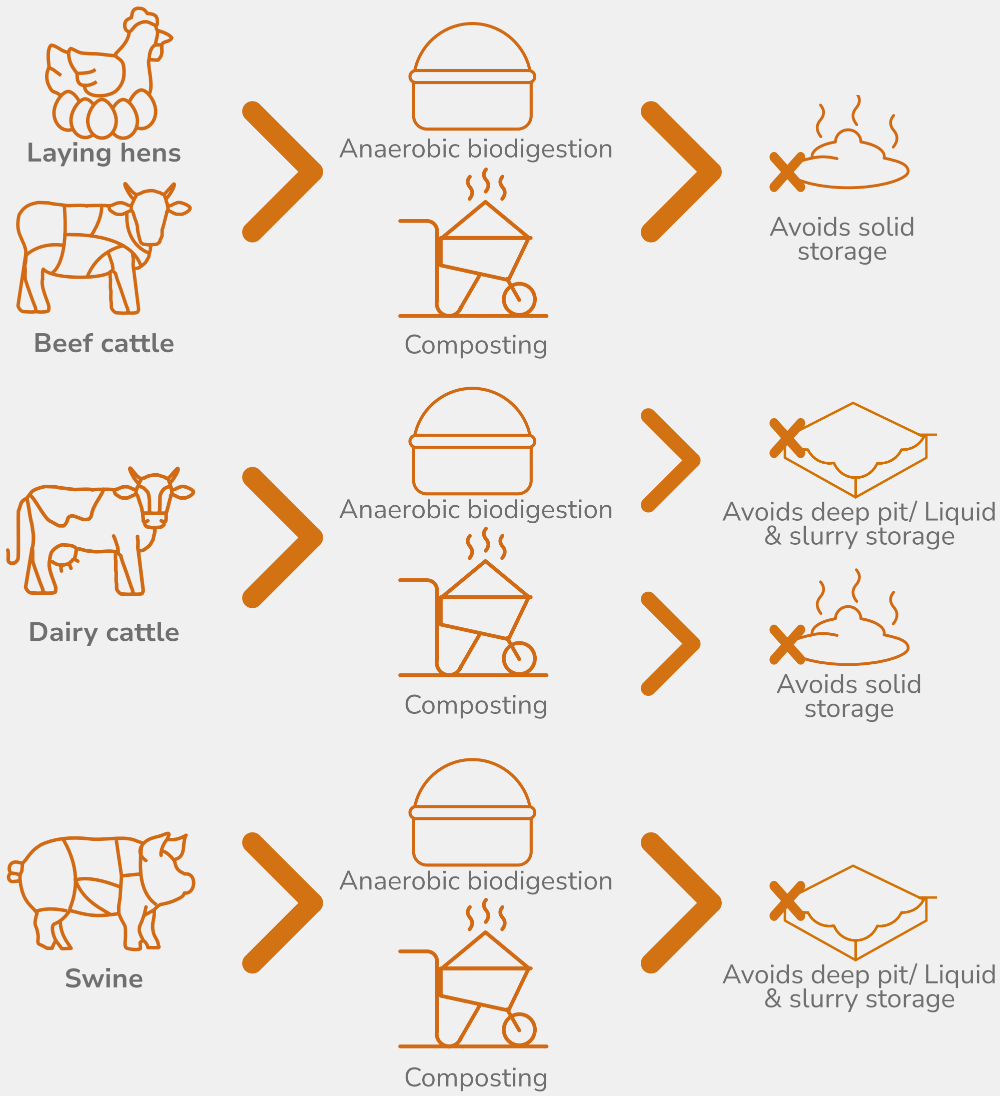
Table 2. **Methane emission factors ($gCH_4/kgVS$) by management technique and climate condition**

Animal category	Management technique	Methane emission factors ($gCH_4/kgVS$)		
		Cold	Temperate	Warm
Dairy cattle	Uncovered anaerobic lagoon	78.8-107.7	117.4-122.2	122.2-128.6
	Liquid/slurry storage > 1 month	22.5-41.8	59.5-65.9	117.4
	Pit/solid storage	3.2	6.4	8
	Dry lot	1.6	2.4	3.2
	Daily spread	0.2	0.8	1.6
	Anaerobic biodigestion	3.2	3.7	3.7
Beef cattle	Uncovered anaerobic lagoon	59.1-80.8	88-91.7	91.7-96.5
	Liquid/slurry storage > 1 month	16.9-31.4	44.6-49.4	71.2-89.2
	Solid storage	2.4	4.8	6
	Dry lot	1.2	1.8	2.4
	Daily spread	0.1	0.6	1.2
	Anaerobic biodigestion	2.4	2.7	2.8
Swine	Uncovered anaerobic lagoon	147.7-202	220.1-229.1	241.2-229.1
	Liquid/slurry storage under confinement > 1 month	42.2-78.4	111.6-123.6	177.9-229.1
	Pit/solid storage	6	12.1	15.1
	Dry lot	3	4.5	6
	Daily spread	0.3	1.5	3
	Anaerobic biodigestion	6	6.8	7
Poultry	Uncovered anaerobic lagoon	128-175.1	190.7-198.6	198.6-209
	Liquid/slurry storage under confinement > 1 month	36.6-67.9	96.7-107.1	154.2-198.6
	Pit/solid storage	5.2	10.5	13.1
	Dry lot	2.6	3.9	5.2
	Anaerobic biodigestion	5.2	10.5	13.1

Source: adapted from Table 10.14 of Chapter 10, Vol. 4 of the IPCC [20].

Figure 9 shows how technological pathways are used in various livestock chains, substituting more emission-heavy methods with environmentally friendly options.

Figure 9. **Technological pathways for livestock waste management**



Criteria for selecting technology

In Brazil, both biodigestion and composting are encouraged as sustainable waste management options. However, the choice of technology should consider:

- Volume and type of waste generated;
- Available infrastructure;
- Climate and regional conditions;
- Potential for using by-products energetically or in agriculture; and
- Socioeconomic viability, balancing costs, benefits, and social acceptance.

This type of analysis ensures that the solution is not only **technically feasible** but also economically sustainable and **socially acceptable**.

KEY MESSAGE

Appropriate technologies reduce emissions, generate energy and fertilizers, and provide social benefits. Replacing open liquid systems with controlled alternatives can cut CH_4 emissions by up to tenfold. These options create the basis for adaptive strategies.

Lessons for replication:

1. Map before acting: conduct a thorough analysis of how waste is generated, stored, and managed in each part of the value chain. This ensures that the chosen technology is based on reliable information.

2. Prioritize the largest emitters: uncovered anaerobic lagoons and manure deep pits should be the initial targets, as they contain the most methane.

3. Adapt technology to the context: biodigesters work best in concentrated areas with liquid waste, while composting is more suitable for systems that produce solid residues, such as poultry.

4. Value co-benefits: besides reducing emissions, highlight advantages such as renewable energy generation, biofertilizer production, and greater social acceptance of the activity.

5. Implement gradually: integrate solutions into existing routines to increase producer adoption and avoid economic or operational disruptions.

3.5 Strategies and potential adaptations across various contexts

With diagnoses and technologies at hand, the final step is to turn information into **strategies tailored to each country's specific context**. Mapping animal production systems involves identifying where, how, and under what conditions herds are raised by cross-referencing production, territorial, and GHG emission data. More than just a technical diagnosis, this mapping provides the foundation for strategic mitigation and adaptation decisions in the livestock sector.

The Brazilian experience shows the value of this method: by combining agricultural and environmental data, it was possible to identify which production systems emit more, such as intensive feedlots, and to assess emission intensity by animal category, including poultry, swine, and cattle. This differentiation offers practical evidence to shape climate policies at the national, regional, and local levels.

The following are the universal principles of mapping animal production systems:

1. **Starting point:** mapping value chains and production systems is the initial step in any national mitigation strategy for the livestock sector.
2. **Robust data:** reliability relies on high-quality statistics. Data gaps can undermine diagnoses and restrict access to climate finance.
3. **Regular censuses and inventories:** frequent updates of agricultural censuses, GHG inventories, and monitoring systems enhance policy credibility and strengthen international commitments.
4. **Intensive systems:** generate large amounts of waste, forming hotspots with greater impact and more immediate mitigation potential.
5. **Extensive systems:** although spread out, they cover large areas and serve millions of people; they cannot be ignored.
6. **Prioritization criteria:** setting clear criteria (e.g., emission volume, social relevance, cost–benefit analysis) enhances policy legitimacy and reduces methodological disputes.
7. **Intersectoral coordination:** turning diagnoses into policies requires collaboration among agriculture, environment, energy, finance, and planning.
8. **Local adaptation:** international methods offer useful guides but must always be customized to each country’s productive, climatic, and institutional conditions.
9. **Continuous updating:** mapping must stay current with changes in markets, climate, and production intensification, remaining a dynamic management tool.

Understanding where emissions occur and how they are distributed between intensive and extensive systems highlights the strengths and weaknesses of each mapping method. This analysis is vital so policymakers can adjust their strategies to match their country's specific circumstances, balancing technical precision and practical feasibility.

Table 3 below presents the main advantages, limitations, and recommendations for using animal production system mapping side by side.

Table 3. **Advantages and limitations of animal production system mapping**

ADVANTAGES	LIMITATIONS	RECOMMENDATIONS
Supports efficient resource allocation, prioritizing the most relevant value chains.	Depends on availability of updated data, often scarce in developing countries.	Encourage regular censuses and inventories as a precondition.
Facilitates territorialized planning, connecting production hubs to public policies.	May overlook smaller but socially relevant chains (e.g., sheep in semi-arid areas, buffalo in wetlands).	Combine volume criteria with social/regional relevance.
Enables comparative analyses between species and regions, useful for international reports.	Multiple criteria may generate methodological disputes and differing interpretations.	Establish a participatory and transparent methodology.
Creates a solid basis for integration with national inventories and climate commitments.	Excessive emphasis on volume may oversimplify analyses and neglect social and environmental factors.	Use complementary social and environmental indicators.

The mapping methodology can be customized for different national contexts by considering three key factors: (i) the dominant production structure; (ii) data availability and quality; and (iii) each country's climate priorities.

In the examples below, we demonstrate mapping practices applicable across different continents, each illustrated with national case studies. The goal is to show how the same approach can be adapted to various contexts while keeping its comparative value and practical usefulness for public policies.

Examples of regional applications:

- **Integrating censuses and inventories to differentiate between concentrated and dispersed emissions.** Example: in the USA and Canada, merging extensive pastures (Great Plains) with intensive feedlots (Midwest), along with concentrated poultry and swine farming, shows how cross-referencing agricultural censuses with GHG inventories helps identify diffuse sources versus specific production hubs.
- **Differentiate regional policies for extensive systems and export-focused chains.** For example, in Argentina, Colombia, and Uruguay, extensive beef cattle farming exists alongside intensive poultry and swine hubs aimed at exports. Mapping allows for policy adjustments tailored to extensive (territorial) and intensive (technological and sanitary) environments.
- **Contrasting approaches between high-density regions and semi-extensive systems.** Example: in the European Union and Eastern Europe, countries like the Netherlands, Denmark, and Germany have high densities of swine and dairy cattle, while the Mediterranean and other parts of Eastern Europe maintain semi-extensive systems. This emphasizes the need to adopt technological measures in high-density areas and territorial management strategies where production is more spread out.
- **Hybrid diagnoses combine intensive hubs with dispersed family production.** Example: in China and Vietnam, intensive hubs for swine and poultry dominate; in South Asia (India, Bangladesh, Pakistan), family-based dairy production is scattered and small-scale. Merging detailed data on concentrated hubs with indirect indicators of family systems ensures diagnoses suitable for both contexts.
- **Participatory methodologies and indirect indicators are valuable in regions with limited official data.** For instance, in African countries such as Ethiopia, Kenya, Uganda, and the Sahel region, pastoralism and extensive livestock farming are widespread, with emissions distributed over large areas. The Brazilian experience shows that even broad scenarios can highlight critical areas; in this context, participatory approaches and indirect indicators make mapping more feasible.

- **Mapping animal production systems is a strategic tool for climate policies.** It helps identify where emissions occur and how they are distributed across intensive and extensive systems, guiding more targeted actions.

The Brazilian experience demonstrates that integrating censuses, inventories, and territorial data creates a flexible methodological framework suitable for different continents, serving as a reference for national mitigation strategies.

Universal recommendations for policymakers

1. **Turn diagnoses into practical policies:** use mapping results to create mitigation strategies aligned with national and sector priorities.
2. **Develop mechanisms for climate finance:** link mapping to strategies for securing green credit, tax incentives, and international funds.
3. **Ensure coordination across all levels of government:** integrate policies at the national, state/regional, and local levels to improve effectiveness and avoid overlaps.
4. **Strengthen international cooperation** by sharing methodologies, data, and experiences through platforms like the CCAC and the GMI, enhancing comparability and mutual learning.
5. **Value social and sectoral participation:** involve producers, cooperatives, local production clusters, and civil society in the process to ensure legitimacy, promote adoption, and increase the chances of successful implementation.

KEY MESSAGE

Mapping production systems should be translated into consistent public policies, supported by climate finance, intersectoral coordination, and international cooperation. This approach connects the analysis of production systems and the identification of priorities with institutional and financial solutions.

Checklist for Chapter 3

☐ Identify priority value chains	Guide actions toward systems with the greatest climate impact and mitigation potential.
☐ Characterize production systems	Differentiates levels of intensification to enable solutions tailored to local conditions.
☐ Quantify and classify waste	Lay the foundation for estimating emissions and choosing suitable management strategies.
☐ Map existing practices	Identify production hubs and data gaps to enhance regional diagnostics.
☐ Choose appropriate technologies	Ensure that public policies are based on viable, replicable solutions with proven climate results.
☐ Adapt strategies to context	Align interventions with production levels and infrastructure availability.
☐ Convert diagnoses into public policies	Transforms technical evidence into practical steps for incentive programs and management actions.

4 STRATEGIC ASSESSMENT: ESTIMATING NATIONAL WASTE VOLUME AND ITS ENERGY POTENTIAL

Chapter 3 showed how to map value chains, systems, and waste volumes to find the largest opportunities for mitigation. The next step is to turn this diagnosis into specific technical and institutional solutions that can quickly, cost-effectively, and with multiple benefits, reduce CH_4 emissions.

The solutions are divided into two complementary areas.

- **Technological** waste treatment and recovery methods, such as biodigestion, composting, co-digestion, and integrated management, not only reduce emissions but also produce bioenergy and biofertilizers.
- **Institutional:** regulatory frameworks, economic incentives, financing strategies, and governance approaches that encourage broader adoption of technologies and their integration into agricultural, energy, environmental, and health policies.

The Brazilian experience demonstrates that combining these two factors increases the chances of success. Green rural credit programs, regulatory requirements for large producers, and cooperation efforts between the public and private sectors are examples that can be customized to different contexts.

At the national level, the ABC Plan, established in 2010 and now in its second phase — ABC+ (2020–2030) — combines rural credit, technical training, applied research, and emission monitoring to encourage the adoption of low-emission technologies in agriculture and livestock. At the subnational level, the state of Paraná has implemented RenovaPR (since 2021), a program regulated by state decree and ordinance that prioritizes biogas and biomethane (alongside other renewable sources). It brings together government agencies, cooperatives, and financial institutions in a scalable framework that links credit, regulation, and technology adoption in the field [22].

The shift from a sectoral diagnosis to a mitigation strategy involves estimating the amount of waste generated, its location, and its potential for energy recovery and biofertilizer replacement. This chapter provides a step-by-step method that can be applied in different countries to organize this process.

The methodological choice in this guide starts with biodigestion — not because it is the only technological option available, but because it effectively converts waste into renewable energy and biofertilizer replacements in a clear and measurable way, serving as a replicable example. However, the same steps outlined here can be adapted to other management methods, such as composting or direct agricultural application.

The goal is to show how livestock data can be turned into technical and energy indicators that shape public policy, by combining herd details, zootechnical coefficients, and energy conversion factors with practical criteria for prioritizing territories.

KEY MESSAGE

Technical and institutional solutions must be integrated; technologies without political support will not spread, and policies lacking technical foundation cannot last. This chapter explains how to transform diagnoses into flexible, scalable actions, drawing on the Brazilian experience across various contexts in the Global South.

4.1 Are there any new and reliable data on the national herd?

The first step in estimating the energy potential of livestock waste is to determine the number of animals, their locations, and the production systems they are part of. Without this information, any projection risks being inaccurate and less effective for guiding public policies.

In most countries, the main source is the national agricultural census, which provides detailed data on the number of animals in each chain, production systems, and farm profiles. However, these censuses are infrequent — every 10 years — and may not reflect recent changes in production. Therefore, it is recommended to combine multiple data sources to improve the accuracy of the estimate.

- National GHG emission inventories (when available).
- International databases such as FAO and OECD[8].
- Academic and sectoral studies, produced by universities, research centers, and producer associations.
- Independent monitoring systems, which update emission estimates annually.

This triangulation enhances the accuracy of estimates and helps identify information gaps that should be addressed in future censuses or inventories. In countries with limited statistical capacity, even sample surveys or participatory methodologies can serve as valuable starting points.

[8] The Organisation for Economic Co-operation and Development (OECD) is an international body composed of 38 countries that produces studies, statistics, and policy recommendations in areas such as economy, environment, energy, education, and trade. The OECD maintains statistical databases and comparative methodologies that can complement national and international data, especially when agricultural censuses or detailed emission inventories are lacking. For example, some countries in the Global South still do not have updated inventories of livestock emissions; in such cases, OECD data can serve as a reference point or to calibrate estimates.

Another common challenge is the lack of data disaggregation. Many statistics only report the total number of animals without indicating whether they are in subsistence, extensive, semi-intensive, or confined systems. This gap makes it hard to accurately identify waste concentration hubs where technological interventions would be most effective.

How can I close this gap?

One practice adopted is setting **cut-off criteria** to filter out establishments with lower energy recovery potential. These criteria may be based on herd size, productivity, or available infrastructure. This prevents overestimating the national potential and emphasizes systems with greater climate and energy significance. In practical terms, these cut-off criteria **serve not only as a diagnostic tool** but also as an initial filter for **energy and economic feasibility,** highlighting where projects are more likely to be sustainable.

PRACTICAL EXAMPLE

In Brazil, a combination of sources was used: (i) the IBGE Agricultural Census, (ii) the annual Municipal Livestock Survey (MLS), and (iii) data from sectoral associations. To update figures through 2024, linear regression was applied to historical data. Additionally, cutoff criteria were set to include only establishments with higher potential for technical feasibility (Table 4).

Table 4. **Cut-off criteria for estimating biogas potential by production system**

Confined production system	Initial sampling
Swine (breeding and finishing)	>500 animals
Laying hens	>10,000 animals
Dairy cattle	>201 cows and productivity >2,000 L/cow/year
Beef cattle	>1,600 animals

This initial filtering had two positive effects: (i) it lowered the risk of overestimating biogas potential by removing subsistence or small-scale establishments, and (ii) it improved the practical relevance of the results, focusing the analysis on settings where management and treatment technologies are feasible.

KEY MESSAGE

Reliable and detailed data on the national herd are crucial for accurate estimates of waste and energy potential. Without this data, mitigation policies become vulnerable. Investing in official statistics and integrating them with other sources strengthens both technical and political credibility of projections.

Lessons for replication

1. Review the diagnosis created in earlier steps: ensure that global (Chapter 2) and national (Chapter 3) data have been consistently integrated before applying territorial filters.

2. Prioritize spatial disaggregation of data: avoid relying on national averages that hide waste concentration hubs where technology adoption is more feasible.

3. Define objective cut-off criteria: set minimum thresholds for scale or infrastructure, such as the number of animals, productivity, or installed capacity, to ensure technical and economic feasibility.

4. Adjust criteria to reflect the national context: consider governance, available infrastructure, local climate priorities, as well as the level of intensification and farm size.

5. Minimize distortions in estimates: by using consistent filters that improve analysis accuracy and make them more valuable for public policy, investors, and financiers.

4.2 Are the zootechnical coefficients for waste and biogas production suitable for the national context?

After determining the herd size, the next step is to estimate **how much waste each animal produces and its potential for biogas generation.** These values are expressed as **zootechnical coefficients**, which vary depending on species, production system, and management conditions. They also fluctuate based on diet, how long animals stay in the unit, and genetic traits. Using inaccurate values can lead to overestimations or underestimations, which can compromise both the design of technologies and the viability of projects.

In many countries, international average values published by organizations such as the FAO and the IPCC are used. These figures are helpful as a starting point, but can cause distortions if applied directly to local situations. Examples of risks include:

- In tropical regions, CH_4 emissions from waste lagoons are much higher than in temperate climates because of higher average temperatures.
- Different diets, whether more forage-based or more concentrated, influence the organic content of manure and, in turn, affect biogas production potential.
- Certain genetics, like cattle breeds suited to the tropics, have different productivity levels compared to reference countries in colder climates.

For this reason, coefficients should always be calibrated using national data collected through scientific research, sector reports, or field monitoring. When complete local data series are unavailable, it is recommended to:

- Begin with international averages as a reference point, then adjust them with regional data.
- Encourage validation studies in major production hubs, which can serve as a foundation for generalizing results.
- Implement varied values based on climate and production system instead of applying a single coefficient nationwide.

Besides typical waste generation, another important factor is having a steady supply year-round.

- **Intensive and confined systems,** such as swine farming, laying hens, and dairy cattle, tend to produce waste consistently and steadily, which supports the operation of biodigesters and other treatment systems. Interruptions, like sanitary breaks in poultry and swine farming, are usually planned and brief.
- **Extensive or semi-intensive systems**, however, tend to experience stronger seasonality. In extensive beef cattle systems, for example, recoverable waste production is smaller, more dispersed across the region, and heavily dependent on the rainy season, which reduces predictability and complicates logistics.

This mapping not only improves the accuracy of biogas potential estimates but also helps identify situations where waste flow is insufficient or irregular. In such cases, alternatives like co-digestion with other organic residues — including those from different animals, food waste, agro-industrial effluents, or crop residues — can enhance biodigestion efficiency, stabilize biogas production, and increase energy output. Therefore, detailed knowledge of zootechnical coefficients becomes not just a methodological requirement but also a valuable tool for guiding more effective technological strategies.

Furthermore, recycling manure and digestate as fertilizer should be managed based on crop needs and soil capacity, since improper application can cause environmental issues. When applied correctly and in appropriate amounts, following agronomic guidelines, animal manure and digestate can effectively replace mineral fertilizers, increase crop yields, improve soil quality, and lower production costs. However, overapplication – exceeding what soils and crops can absorb – may lead to serious environmental problems, such as greenhouse gas emissions, nutrient leaching, and soil contamination [23].

PRACTICAL EXAMPLE

Several studies have already established reference values for the main livestock sectors and their biogas potential in Brazil. Table 5 presents average factors for effluent generation and biogas production by animal category. These figures illustrate how local data can be organized to support national projections but should always be viewed as reference points that need to be adapted to the specific context.

Table 5. **Factors influencing animal waste generation and biogas production in Brazilian livestock**

Category	Production cycle of the unit (days/year)	Waste generation factor (m^3 waste/year/animal)	Biogas production factor (Nm^3 biogas/animal/year)
Swine – finishing	347.2	1.54 [a]	34.64 [f]
Swine – breeding	365	4.16 [a]	51.43 [f]
Laying hens	365	0.04 [d, e]	5.11 [d]
Dairy cattle	365	15.14 [b, c]	264.01 [f]
Beef cattle	365	8.76 [b, c]	203.85 [f]

Source: a[24]; b[25]; c[26]; d[17]; e[27]; f[28].

These figures should always be treated as reference values, not fixed ones. They can fluctuate based on factors such as:

- Animal diet;
- Production system (intensive, semi-intensive, extensive);
- Length of confinement;
- Climatic conditions; and
- Genetics and herd productivity.

KEY MESSAGE

Using international coefficients without calibration can lead to inaccurate estimates. Adjusting to national factors — including climate, diet, genetics, and production systems — is essential for generating reliable waste and biogas projections.

Lessons for replication

1. Use international coefficients only as a preliminary reference: they provide comparability but need adjustment.

2. Verify with national data whenever possible: academic research and sectoral reports enhance accuracy.

3. Differentiate coefficients based on climate and production system to reduce errors caused by using a single value across different conditions.

4. Establish validation hubs: field measurements allow for more accurate extrapolation of results to other regions.

5. Periodically update national coefficients: changes in genetics, management, and feeding affect waste profiles and energy potential.

4.3 Is the projection regionalized to guide regional public policies?

A national projection of livestock waste, energy, and biofertilizer potential becomes truly useful only when regionalized, meaning it shows how animal populations, waste volumes, and emissions are distributed geographically. This step allows us to convert statistics into practical information for public policies, regional investments, and mitigation strategies.

Without regionalization, efforts may focus on less relevant areas or overlook key production centers that generate the most waste. For example, a country might have a large national cattle herd, but only certain regions, such as feedlot hubs, offer significant opportunities for emissions reduction and energy recovery. In other words, regionalization helps prioritize where biogas and biofertilizer production are most practical, thereby reducing the risk of wasting resources on areas with low efficiency and high potential benefits.

Spatial disaggregation, whether by mesoregions, microregions, provinces, or districts, depending on each country's reality, enables policymakers to identify priority hubs, reduce statistical asymmetries, and customize solutions to local conditions.

When results are displayed in a regional format, it helps answer important questions such as:

- Where are the largest confined herds located?
- Which regions already have infrastructure that can be utilized?
- Where will implementing biodigesters or composting have the largest immediate impact?

To achieve this, apply regional cut-off criteria such as animal density, level of confinement, proximity to electricity and gas infrastructure, and agricultural production areas for using biofertilizers, since these factors narrow the gap between technical estimates and practical implementation. This approach highlights that estimating a country's overall potential is not enough: it is crucial to identify who, where, and how services should be prioritized first.

Tools for regionalization and implementation tips:

- **Municipal or regional livestock maps:** developed from agricultural censuses or regular statistical surveys (e.g., municipal livestock surveys in Brazil, agricultural surveys in India and Ethiopia).
- **Subnational emission inventories:** developed by local governments, universities, or independent systems (e.g., regional emission estimates in Latin America and Asia).
- **Georeferenced data on agricultural establishments:** when available, allows detailed analysis by farm or production hub (e.g., rural land registries in Brazil, land-use maps in Indonesia and Nigeria).

Implementation tip: when launching a national program, target regions with a strong presence of confined chains and existing infrastructure, such as cooperatives, agro-industries, and rural electrification cooperatives. This approach increases the chances of economic viability and speeds up results.

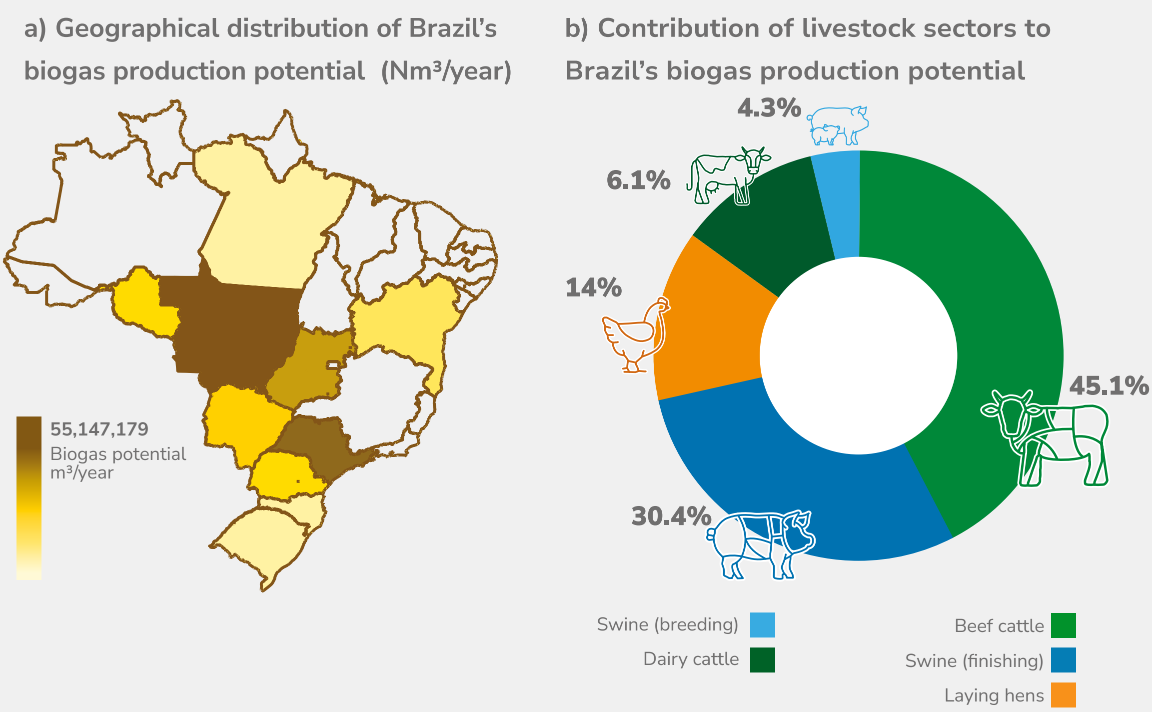
PRACTICAL EXAMPLE

The total Brazilian technical potential for biogas production was estimated at 2.8 billion Nm³/year, with the highest concentration in the South, Southeast, and Midwest regions (Figure 10). Only five states — São Paulo, Mato Grosso, Santa Catarina, Goiás, and Paraná — account for 65.8% of the national potential. These areas combined:

- High animal density;
- Strong presence of confined chains (swine, cattle, poultry);
- Consolidated agricultural infrastructure; and
- Favorable logistics for distributing energy and biofertilizers.

This regional breakdown shapes policies and investments starting from key impact hubs. In the breakdown by value chains (Figure 10), beef cattle and finishing swine together make up more than half of the national potential, followed by laying hens, dairy cattle, and breeding swine.

Figure 10. **Biogas potential in Brazil by region and by livestock chain**



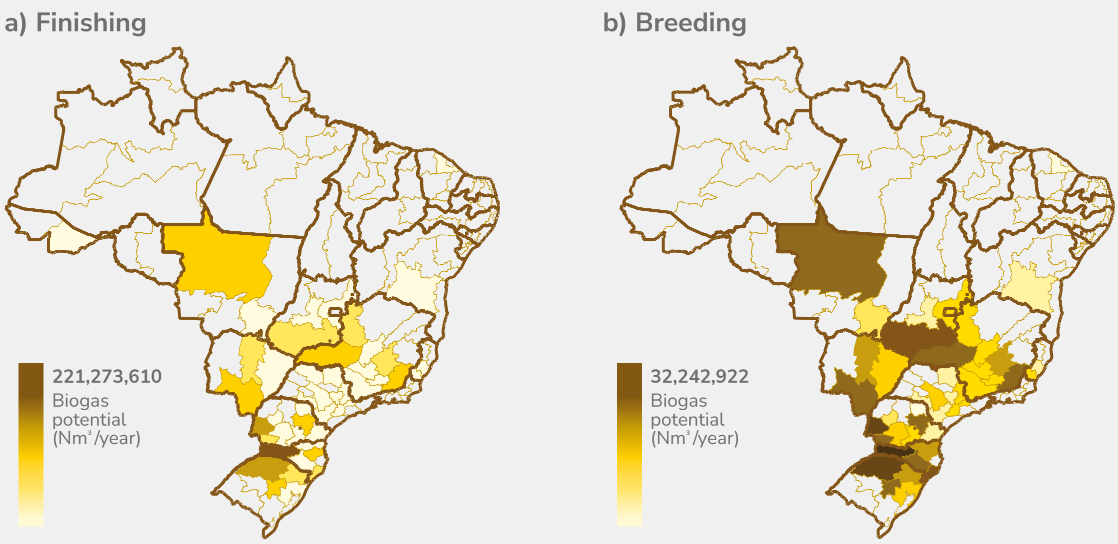
Beyond the overall view, it is important to analyze the geographic distribution by sector. Identifying the micro- and mesoregions where each animal category contributes most to biogas potential enables the development of more effective mitigation strategies, promotes the co-digestion of residues, and guides the planning of centralized biodigesters that can serve nearby communities.

Examples of regional application

- **Swine (finishing)** is primarily located in the South, representing 70.7% of the national total. The western part of Santa Catarina serves as a key hub, with strong agro-industrial integration (Figure 11).
- **Swine (breeding)** follow the same regional pattern, strengthening the strategic synergy across production phases (Figure 11).
- **Laying hens** are more spread out, with São Paulo leading at 37% of the total, along with Espírito Santo and Minas Gerais (Figure 12).
- **Dairy cattle** are more widely distributed, with hubs in the Triângulo Mineiro[9] , Central Goiás (Figure 13a).
- **Beef cattle** are mainly located in the Midwest and Southeast, accounting for nearly 80% of the total, but there is untapped potential in extensive systems (Figure 13b).

These examples show how regionalization shapes different choices across the value chain: in swine farming, collective and cooperative setups; in poultry, dispersed regional approaches; in cattle, a focus on beef feedlots and increasingly advanced dairy farms.

Figure 11. **Regional biogas potential of swine systems**



[9] Triângulo Mineiro is a mesoregion located in the western part of Minas Gerais state, Brazil. It is one of the country's main hubs for dairy and beef production, with a strong presence of confined cattle systems and agricultural infrastructure.

Figure 12. **Regional biogas potential of laying hens**

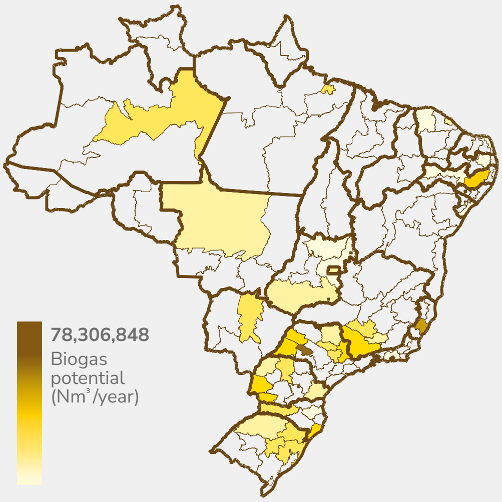
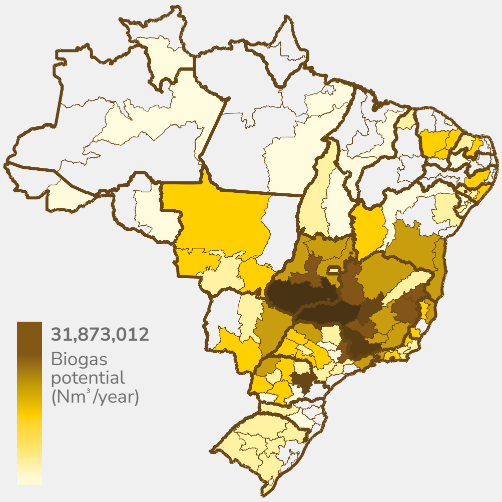
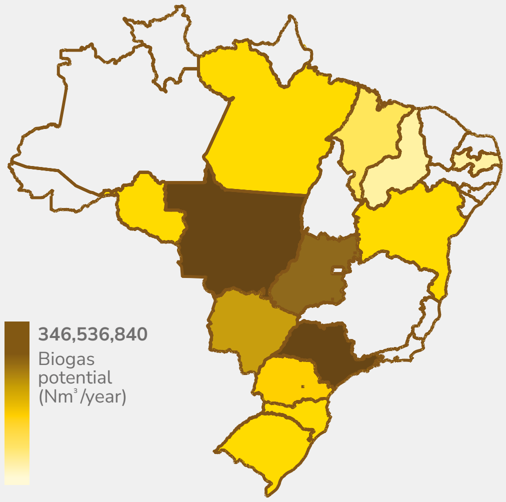


Figure 13. **Regional biogas potential of cattle**

a) Dairy



b) Beef



This regionalized approach guides different policies: incentives for biodigestion in areas with confined swine and cattle, composting in poultry hubs, and pasture management in extensive cattle regions.

KEY MESSAGE

Regionalization transforms overall data into valuable insights for local public policies. Without it, national forecasts have limited practical value. Subnational maps and inventories help pinpoint where each technology is most feasible and impactful.

Lessons for replication

- **Break down national projections by region:** convert aggregate data into disaggregated data that allows the creation of regional maps to support public policies and investments.

- **Use subnational sources whenever available:** municipal surveys, regional inventories, and independent systems enhance the accuracy of estimates.

- **Identify key production hubs:** concentrate efforts on regions with the highest waste density, where mitigation provides the greatest benefits.

- **Adopt region-specific policies:** apply advanced technologies in high-density areas and develop territorial management strategies in extensive systems.

- **Regularly update diagnostics to** keep projections accurate with herd size, markets, and climate changes.

- **Prioritize regions with existing infrastructure:** cooperatives, agro-industries, and rural electrification networks enhance economic viability and accelerate results.

4.4 What kinds of energy can come from livestock waste?

Animal waste can be utilized in many ways, from simple methods like composting or direct application as fertilizer to more advanced options such as generating energy through biogas. Each method offers benefits, challenges, and specific technical requirements, which depend on factors like production scale, waste characteristics, livestock system type, existing infrastructure, and regional conditions.

This guide highlights biogas production because it most directly helps reduce methane emissions, is relevant across different value chains, and offers multiple energy options. However, remember that the methods shown can be adapted for other uses, as long as they suit the national context.

Possible energy routes include:

- **Electricity:** Biogas can be converted into electricity using generator sets. This approach is especially vital in rural areas, as it enables decentralized supply, reduces energy costs, and can even generate marketable surpluses.
- **Thermal energy:** The heat produced by biogas combustion can be used in local manufacturing processes, such as drying grains, heating poultry houses and hog nurseries, milk pasteurization, or water heating. This method is simple, effective, and can directly lower producer expenses.
- **Biomethane:** After a purification process (upgrading), biogas can be converted into biomethane, which has the same quality as natural gas. Biomethane can be used as vehicle fuel, as a diesel replacement in agricultural fleets, or injected into pipelines, supporting integration with national energy systems.

Besides energy, biodigestion creates digestate, a nutrient-rich biofertilizer with varying nutrient levels depending on the feedstock, containing beneficial microorganisms for plants. It can partially substitute synthetic fertilizers and reduces farming costs.

How can you make the numbers more tangible?

To ensure that projections are not limited to technical units that are harder to understand, such as normal cubic meters per year (Nm^3 of biogas/year), it is advisable to convert results into easily understood **energy equivalents**. This conversion is crucial for effectively communicating potential to **decision-makers**, **investors**, and **society**, helping to strengthen the case for feasibility.

- **Number of households**[10] that can be supplied with generated electricity;
- **Liters of diesel**[11] that could replace agricultural fleets, public transportation, or freight vehicles.
- **Metric tons per year (t/year) of chemical fertilizers**[12] that could be replaced by digestate from biodigestion.

[10] Average household composition and electricity consumption. In developing countries, the average household has 4–6 members. Typical electricity use ranges from 30–120 kWh per month, depending on access and income. Rural households generally consume 1–3 kWh per day, mainly for lighting, refrigeration, and phone charging.

[11] Average diesel consumption per engine. Agricultural and transport engines in developing regions use about 4–6 liters of diesel per hour for medium tractors or generators. Annual use per unit averages 3,000–6,000 liters, varying with farm size and operating hours.

[12] Average fertilizer replacement with digestate. Digestate from biodigesters can replace 0.3–1.0 t of chemical fertilizer per year per household or small farm, providing equivalent nitrogen, phosphorus, and potassium for 0.5–1 hectare of crops. Larger systems can offset several tonnes annually.

These simple, comparative metrics help illustrate the value of investments in waste recovery technologies, making the climate, energy, and economic benefits clearer and easier for investors and decision-makers to understand.

The calculation of energy equivalencies depends on using internationally recognized parameters, such as:

- Calorific value of methane: ~9.97 kWh/Nm³ CH_4 [29];
- Average efficiency of generator sets: 30–40% [30];
- Upgrading efficiency for biomethane: >97% [31];
- The average methane content in biogas is 55–65% [32].

These values should always be tailored to the local context by considering factors like the average waste composition, climate, and production levels. Using these parameters enables comparison of different scenarios and helps convert energy potential into indicators that more accurately reflect the realities of the productive sector and public policies.

PRACTICAL EXAMPLE

In Brazil, the technical potential for biogas is estimated to supply about **1.8 million households** annually with renewable, decentralized electricity. The same energy, converted into biomethane, could replace roughly **2.0 billion liters of diesel**, reducing logistics costs and greenhouse gas emissions. In reality, part of this potential is already being utilized. In southern Brazil's swine farming, biodigester projects turn waste into biogas, which is then used to generate electricity in cooperatives and agro-industries. The resulting digestate is applied to corn and soybean crops, replacing imported chemical fertilizers. This model, adaptable to other countries in the Global South, shows how to combine energy security and food security into a single solution.

KEY MESSAGE

Livestock waste can be transformed into electricity, heat, biomethane, and biofertilizers. This diversification boosts environmental, energy, and economic advantages, making mitigation systems more attractive and easier to adopt.

Lessons for replication

1. Diversify energy sources: assess electricity, heating, biomethane, and cogeneration according to local market profiles.

2. Integrate energy and fertilizer production: use digestate as a biofertilizer to improve food security and reduce costs related to chemical inputs.

3. Adapt to scale and infrastructure: smallholders might use biogas for cooking and heating, while large cooperatives could invest in cogeneration or biomethane.

4. Explore fossil fuel substitution markets: biomethane can replace diesel in fleets and natural gas in pipelines, reducing emissions and costs.

5. Ensure economic sustainability: link energy projects with organized agro-industrial chains (cooperatives, consortia) to make investments viable and encourage their expansion

BOX 4 | **WHY CAN OPEN FLARES WORSEN EMISSIONS?**

The flaring of biogas in ***open flares*** *(or simple burners) is, in many cases, presented as a "modern" solution for reducing emissions. However, when poorly applied, these devices can generate more pollution than a conventional manure lagoon.*

Why does this happen?

- ***High methane production from biodigesters:*** *biodigestion rapidly converts large volumes of waste into methane-rich biogas, which is desirable for energy purposes.*
- ***Low combustion efficiency in open flares:*** *open flares burn biogas incompletely, often with efficiency below 50% [33]. Much of the* CH_4 *escapes unburned.*
- ***Higher net climate impact:*** *when concentrated methane is not efficiently destroyed, the climate effect can be worse than gradual decomposition in lagoons, which also release* CH_4 *but at a slower rate.*

MAIN TAKEAWAY

Capturing biogas only makes climate sense if it is properly utilized. Closed flares — or preferably, conversion into electricity, heat, or biomethane — ensure CH_4 *destruction efficiency above 98%, while substituting fossil fuels and generating environmental, economic, and social benefits.*

4.5 Beyond technical feasibility, does the technology also offer economic viability?

The feasibility of livestock waste recovery projects depends not just on technical calculations of the biogas or biofertilizer that can be produced. The main factor for large-scale adoption is **economic viability**. This is because these systems require significant **initial investments in infrastructure (CAPEX)** and **ongoing operating costs (OPEX)**. Therefore, before conducting detailed studies, it is advisable to carry out a **pre-feasibility economic analysis**, which acts as an initial filter to identify projects most likely to yield positive returns.

Main cost components:

- **Initial investment (CAPEX):** constructing biodigesters, biogas purification systems, generator sets, or cogeneration units.
- **Operation and maintenance (OPEX):** skilled labor, part replacements, monitoring, and control.

- **Logistics:** waste transportation, biofertilizer distribution, and integration into the electricity or gas grid.

Sources of revenue and savings:

- **Input substitution:** reducing costs by switching from chemical fertilizers and fossil fuels.
- **Sale of surplus energy:** electricity, biomethane, or heat to neighbors, cooperatives, or local grids.
- **Carbon credits and green financing:** projects can earn rewards for reducing CH_4 and N_2O emissions.
- **Indirect economic co-benefits:** odor management, greater social acceptance, and potential new revenue sources for producers.

PRACTICAL EXAMPLE

Technical studies carried out in Brazil show that the payback period for agricultural biodigesters can vary greatly depending on production scale, management style, and the amount of by-product used. Integrated systems — such as those organized around cooperatives, agribusinesses, or producer groups — demonstrate that biodigesters can recover their investment in roughly three to six years [34; 35], although longer times might be needed for certain scales [36]. Conversely, small and isolated farms, which lack scale or integration into organized value chains, generally experience longer payback periods and depend more on technical assistance, rural credit, and public policies to make investments feasible [37].

The economic viability of biogas projects relies on several factors. Table 6 highlights the most favorable conditions, common risks and limitations, and how each variable can either promote or impede adoption in various countries.

Table 6. **Conditions influencing the economic feasibility of biogas projects**

Factor	Favorable condition	Risk/limitation
Production scale	High animal density (swine, poultry, confined cattle)	Dispersed small scale – high unit costs
Infrastructure	Presence of cooperatives, electricity or gas grids	Geographic isolation – commercialization not feasible
Policies & incentives	Feed-in[13] tariffs, carbon credits, green financing	Lack of incentives – slow returns
Biofertilizer market	Partial substitution of synthetic fertilizer	Low prices – limits value capture

This table presents common factors used in feasibility analyses in Brazil, but the same model can be adapted to other countries in the Global South. It is recommended to tailor variables such as herd size, energy and fertilizer prices, infrastructure availability, and incentive policies according to local conditions and data.

[13] Economic incentive mechanism used by governments to promote renewable energy generation.

4.5.1 How to structure a pre-feasibility analysis?

Before starting detailed studies, performing a pre-feasibility analysis helps determine whether a biodigester or composting project is financially feasible. This step serves as an initial filter, which is especially crucial in countries of the Global South where resources for investment are limited. The analysis can be divided into four main stages.

1. Collect basic data

Gather the minimum information required to start calculations:

- ***Initial investment (CAPEX):*** civil works, pre-treatment systems (pumps, screens, separators), biodigesters (covered lagoon or continuous stirred-tank reactor, CSTR), biogas treatment (desulfurization, drying, filtering), and end-use systems (electricity generation, biomethane, or thermal use). Include commissioning, training, and integration.
- ***Reinvestments:*** equipment has different lifespans (e.g., covered lagoon ≈ 15 years; CSTR ≈ 25 years) and will require replacement over time.
- ***Operating costs (OPEX):*** electricity, chemical inputs (activated carbon, lubricants), labor, and maintenance.
- ***Potential revenues:*** include savings from self-generated energy, sales of electricity or biomethane, waste treatment gate fees, carbon credits (e.g., voluntary credits), and biofertilizers.
- ***Context indicators:*** include inflation, local energy and fuel prices, available credit lines, and incentive policies.

2. Structure a simplified cash flow

After collecting basic data, the next step is to simulate money inflows and outflows over time to see if the project "pays for itself." This simulation, called a cash flow, can be done in a spreadsheet, even in a simplified version. A pre-feasibility cash flow should include:

- ***Investment costs (CAPEX + reinvestments):*** a substantial upfront expense for construction, equipment, and installation, followed by reinvestments for replacing equipment.
- ***Annual operating costs (OPEX):*** expenses needed to keep the system functioning, such as electricity, chemicals, maintenance, and wages. Adjust these costs for inflation over time.
- ***Estimated revenues include*** energy bill savings, reduced diesel use, sales of energy or biomethane, biofertilizer sales, and carbon credits. Revenues should also be adjusted for price fluctuations.

- ***Annual cash flow:*** each year's balance equals Revenues minus OPEX. Positive balances indicate the project is generating returns.
- ***Cumulative cash flow:*** measures when revenues cover the initial investment. Once the cumulative balance turns positive, the project has achieved payback.

Simplified example: A pig producer spending USD 20,000 per month on electricity can save USD 15,000 each month with a biodigester. With an initial investment of USD 2 million, the cash flow shows how many years of savings (plus fertilizer use) are required to recover the investment.

3. Calculate key economic indicators

Once the cash flow is ready, assess if the project is genuinely profitable. Key indicators include:

- ***Simple or discounted payback period (time to recover):*** shows how many years it takes to recover the initial investment. Example: if the investment was USD 2 million and the project saves USD 500,000 annually, the simple payback is 4 years. Discounted payback considers inflation and the cost of capital.
- ***Net Present Value (NPV):*** measures whether future gains, discounted to the present, surpass costs. A positive NPV indicates the project adds value beyond its expenses.
- ***Internal Rate of Return (IRR):*** the yearly rate of return for a project. If it surpasses the Minimum Acceptable Rate of Return (MARR) set by a country, bank, or investor, the project is deemed profitable.
- ***Return on Investment (ROI):*** measures efficiency by comparing net profit to the initial investment, allowing for comparisons with other options.
- ***Levelized Cost of Energy (LCOE) and Levelized Cost of Biogas (LCOB):*** represent the average cost to produce 1 MWh of energy or 1 Nm^3 of biogas over the project's lifespan. If LCOE is below the local electricity tariff, the project remains competitive.

4. Define decision criteria

Once indicators are calculated, evaluate whether the project is attractive. Criteria may vary by country but generally follow international best practices.

- ***Positive NPV:*** indicates the project creates value above costs.
- ***IRR > MARR:*** return exceeds the minimum required by banks/investors.
- ***Acceptable payback:*** the return period must be reasonable for investors. Cooperatives typically accept 5–7 years, while larger projects might tolerate 10–12 years.

- ***Competitive LCOE/LCOB:*** the average cost of energy or biogas should be equal to or less than market prices for electricity, diesel, or natural gas.

Simplified example: A rural biodigester with a positive NPV, an IRR of 18% per year (above a MARR of 12%), a payback period of 6 years, and energy costs lower than the local rural tariff can be considered economically viable and competitive. Reference values (MARR, fertilizer prices, energy costs) vary by country, but the method is universal and adaptable.

Access the link to open the Biogas Pre-Feasibility Tool, a technical platform that allows users to estimate costs, revenues, and initial payback, and simulate pre-feasibility scenarios for livestock waste management systems.

KEY MESSAGE

Economic feasibility links technical potential to actual adoption. Biodigester and composting projects only proceed after passing the pre-feasibility check, which evaluates initial investments (CAPEX) and operating costs (OPEX) against revenues from energy, fertilizers, and carbon credits. Collective models, regional infrastructure, and public policies greatly improve the chances of success.

Lessons for replication

1. Always start simple: before investing significant time and money into full studies, conduct a pre-feasibility economic analysis. This initial step helps eliminate unviable projects and focus on those with higher chances of success.

2. Look beyond technology: it's not enough for it to work — it also needs to be financially appealing to producers or investors.

3. Adjust numbers to fit your local context: use coefficients and prices from your region (energy, fuels, inputs, credit lines). Copying data from other countries without modification leads to mistakes and unrealistic expectations.

4. Organize calculations in four steps:

- Collect essential data (CAPEX, OPEX, revenues).
- Create a simple cash flow statement.
- Calculate primary economic indicators (payback, NPV, IRR, ROI, LCOE/LCOB).
- Establish decision criteria (to determine when the project is worthwhile).

5. Use local examples to engage: translate results into equivalents, such as energy savings, diesel replaced, and carbon credits generated, to make communication clearer and boost engagement.

6. Focus on contexts with higher feasibility: regions with dense animal populations, expensive or unreliable energy, and established agro-industrial infrastructure often generate more competitive projects.

4.6 Besides technical feasibility, does the technology also have economic feasibility?

Livestock waste-to-energy projects vary widely by country, region, or supply chain, each with its own unique factors such as production capacity, data access, energy infrastructure, and public policies. Therefore, translating technical forecasts into practical national strategies requires a flexible approach. Success ultimately depends on aligning technologies with existing energy and climate policies and developing business and financing models that suit producers' scale and capabilities.

The most common dimensions of adaptation are:

- **Productive structure:** countries with intensive livestock systems (swine, poultry, confined cattle) can adopt biodigestion and cogeneration more quickly, while those with extensive systems should focus on territorial management, fire prevention, and decentralized solutions.
- **Data availability and quality:** countries with robust agricultural censuses can achieve high land accuracy, while areas with statistical gaps can use participatory methods and sample surveys as alternatives.
- **Existing infrastructure:** regions with cooperatives, agro-industries, and rural electrification networks are better equipped to implement biogas projects; in remote areas, the focus may be on local direct uses of biogas, such as cooking or lighting.
- **National climate priorities:** some countries focus on food security and fertilizer production (digestate use), while others view biomethane as a way to decrease reliance on fossil fuels.

PRACTICAL EXAMPLE

Brazil's experience in estimating the energy potential of livestock waste demonstrates that absolute numbers are less important than the analytical methods and criteria used. By combining herd projections, zootechnical coefficients, energy equivalences, and pre-feasibility studies, it is possible to develop realistic scenarios that inform both public policy and investment decisions. Table 7 below summarizes the main advantages, limitations, and recommendations for using estimates of livestock waste energy potential.

Table 7. **Advantages, limitations, and recommendations for using estimates of livestock waste energy potential**

ADVANTAGES	LIMITATIONS	RECOMMENDATIONS
Robust energy potential estimates are used as technical arguments in financing.	Lack of local zootechnical coefficients and conversion factors can undermine credibility.	Use imported coefficients only as a starting reference, always calibrating with national or regional data.
Enables integration with other sectors, facilitates inclusion of agro-industrial and urban residues in codigestion scenarios.	Regions with lower livestock production or extensive systems may be undervalued in surveys.	Align energy potential surveys with GHG inventories, planning, and solid waste policies.
When translated into practical equivalences, it engages producers and decision-makers.	More robust methodologies may be difficult to apply in countries with low institutional capacity.	Beyond the volume of biogas, assess benefits such as odor reduction, job creation, and less water contamination.

Understanding the energy potential of waste and how it is distributed across the territory reveals both opportunities and challenges for each management technology. While values vary between countries, the core principles of the methodology can be applied in different contexts, as long as appropriate adaptations are made.

International examples that reinforce this point:

- **Latin America:** Countries like Colombia and Mexico use biodigesters in swine and poultry farms integrated into agro-industries, but still face challenges expanding to small producers.
- **Sub-Saharan Africa:** Pilot projects in Uganda and Kenya show that small-scale biodigesters are more practical for household uses such as cooking and lighting, supported by subsidized rural credit programs.

These examples show that strategic adaptation is crucial. The same concept — using livestock waste as a source of energy and fertilizer — can take many different forms depending on the local context. In practice, countries have followed different paths, which fall into five main strategies.

- **Strengthen methodological frameworks when data gaps arise.** Example: in Tanzania, FAO used the Bioenergy and Food Security approach to assess bioenergy potential and support policy decisions [38].
- **Focus on updating the national mapping.** For example: in the United States, the EPA AgSTAR program maintains a national database and public map of livestock biodigesters, which are used by states and investors for sectoral planning [39].
- **Use subnational breakdowns to reduce statistical disparities.** Example: in Germany, subnational surveys find rural districts with higher biogas potential, guiding subsidies and incentive policies [40].
- **Plan energy in a decentralized way.** Example: In Uganda, FAO studies on biomass waste management within the Bioenergy and Food Security framework identify bioenergy options for district and sector planning [41].
- **Integrate bioenergy with climate policies and other waste streams.** For example, in the European Union, IEA Bioenergy Task 37 reports provide country-level data (including Denmark and Germany) on plant numbers, production, use, and upgrading, serving as a basis for energy and climate planning [42]. In India, several states are prioritized in bioenergy programs because they concentrate both livestock waste and agricultural residues for codigestion [43].

KEY MESSAGE

There is no one-size-fits-all solution or “silver bullet” that works for everyone. Successful strategies integrate technical standards, economic viability, and adaptation to each country’s production conditions, climate, and institutional framework. The Brazilian experience shows potential pathways, but replicating them depends on the ability to customize priorities, business models, and public policies to fit the local context. In summary, projecting, territorializing, and pricing (pre-feasibility) are the three main pillars for transforming technical potential into a portfolio of viable projects in the Global South.

Lessons for replication

1. Recognize the different contexts: extensive, semi-intensive, and intensive systems require different approaches.

2. Adjust your strategy based on the data available: when detailed censuses are unavailable, rely on sample surveys, participatory methods, and international databases.

3. Leverage existing infrastructure: production hubs with cooperatives and agro-industries serve as strategic entry points for expansion.

4. Align strategies with national priorities: countries might focus on energy security, reducing fertilizer imports, or cutting emissions, depending on their specific goals.

5. Implement gradually: begin with pilots in key regions, expand in priority waves, and make continuous adjustments.

6. Integrate sectoral policies: coordinate agriculture, energy, environment, and finance to transform diagnostics into effective policies.

International experience shows that transforming technical projections into effective public policies requires some basic principles that can be applied in any country:

- **Ensure reliable statistical bases:** agricultural censuses, GHG inventories, and regular monitoring are prerequisites for any solid projection.
- **Validate data and coefficients locally:** imported figures should serve only as a starting point; adjust them to reflect local climate, genetics, diets, and production systems.
- **Adopt clear and transparent cut-off criteria:** define minimum inclusion parameters (herd size, level of technification) to increase legitimacy and facilitate social and political engagement.
- **Translate technical numbers into tangible equivalences:** examples such as "number of households supplied" or "liters of diesel replaced" make communication with producers, managers, and investors easier.
- **Test pre-feasibility before moving forward:** initial analyses prevent wasting resources on projects that are not economically sustainable.
- **Establish periodic update routines:** projections must keep pace with changes in production structure, market prices, and climate to avoid obsolete diagnostics.

KEY MESSAGE

Successful policies depend not only on technology but also on solid information, clear criteria, and accessible communication. Adopting these principles increases the likelihood of transforming diagnostics into effective and lasting investments.

✓ Checklist for Chapter 4

☐	**Check for updated data on the national herd**	Ensures reliable projections and avoids distorted estimates.
☐	**Conduct a preliminary economic analysis**	Saves time and resources by abandoning unfeasible projects early.
☐	**Mapping data by regions**	Helps identify key production centers and informs local public policies.
☐	**Convert technical figures into simple equivalents (households reached, liters of diesel replaced, tons of fertilizer saved)**	Helps engage producers, investors, and managers.
☐	**Define objective cut-off criteria (minimum scale, size, infrastructure)**	Focus efforts on areas with higher climate impact and economic viability.
☐	**Focus on key strategic hubs with existing infrastructure (cooperatives, agro-industries, rural electrification)**	Improves economic returns and accelerates climate efforts results.
☐	**Adapt strategies to the national context**	Ensuring that the proposed solutions align with the country's productive and institutional diversity to increase their effectiveness.
☐	**Integrate sector-specific policies (agriculture, energy, environment, finance)**	Turn technical diagnostics into tools that support the development of public policies and mitigation strategies.

5 HOW TO ADAPT MANURE MANAGEMENT SOLUTIONS TO LOCAL CONDITIONS

Based on the technical projections summarized in Chapter 4, the next step is to turn potential into practical programs. Territorial, climatic, productive, and cultural diversity present both challenges and opportunities for implementing sustainable solutions in livestock manure management.

Technology Reference Units (TRUs) are sites where a technology is implemented at full scale to serve as examples and learning environments. They act as "open-air classrooms," allowing producers, technicians, researchers, and policymakers to see firsthand how a solution works in real life. More than just showcasing innovation, TRUs need to be operational, accessible, and reflective of local conditions. This means they should show real results that can be duplicated on other farms with similar traits.

What are TRUs used for?

- Test and validate solutions in real production environments.
- Establish confidence in technology among producers, investors, and governments.
- Lead by example, encouraging replication on other farms.
- Generate dependable data to guide public policy and investment decisions.

In this process, TRUs play a vital role. They test solutions in real-world environments, produce reliable evidence, and facilitate widespread sharing. Beyond isolated pilot projects, they function as active innovation hubs, linking producers, technicians, policymakers, and investors. The goal of this section is to synchronize three dimensions that need to advance together.

- **Technology:** biodigestion, composting, and complementary methods tailored to each livestock sector and local context.
- **Public policy:** clear rules, achievable targets, incentives, and environmental and social protections.
- **Financing:** business models and funding sources that support investments and ensure long-term operations, while building a portfolio of bankable projects.

The proposed approach is practical and reproducible. It aims to specify **who coordinates**, **how decisions are made**, **which tools encourage adoption, how financing is organized, and how results are tracked** (Monitoring, Reporting and Verification -MRV), always keeping a focus on the territory and involving sectoral stakeholders.

This chapter covers:

- Governance arrangements (intersectoral coordination, roles of ministries, agencies, cooperatives, and the private sector).
- Regulatory and economic tools include standards, targets, incentives, public procurement, and model contracts.
- Financing mechanisms like credit, blended finance, guarantees, and climate funds, as well as business models tailored for various production scales.
- MRV system: monitoring, reporting, and verifying results (emissions, energy, biofertilizers), ensuring transparency and ease of operation.
- Implementation roadmaps in "waves" (pilots → regional scale → national expansion) with risk management and safeguards.

KEY MESSAGE

Technical diagnostics only produce results when there is clear governance, well-designed incentives, sufficient funding, and effective field validation mechanisms. Aligning these elements is what transforms potential into scalable national programs.

5.1 Why should technologies be tailored to local realities?

The projections in Chapter 4 demonstrate the technical potential for energy recovery from livestock manure. The next step is to turn this potential into practical and widely accepted solutions in the area. This requires adapting to the environmental, productive, and sociocultural conditions of each region.

The same technology can produce very different outcomes depending on the context.

- **Climate:** In cold regions, biodigesters need more insulation or heating to work effectively; in hot regions, this might not be necessary.
- **Types of herds** include pigs, cattle, and poultry, which produce manure in different forms (liquid, solid, mixed). This influences the choice of technology.
- **Production scale:** a smallholder farmer cannot match the investment capacity of a cooperative or a large industrial farm.
- **Available infrastructure** such as electricity, roads, technical assistance, and credit can either facilitate or obstruct certain solutions.
- **Business model: i**n areas with expensive and unstable electricity, biogas may be most effective for power generation; near cities, upgrading to biomethane and selling it to the grid could be more beneficial.
- **Social acceptance:** some communities welcome using digestate as fertilizer, while others may resist culturally.

Adaptation does not mean reinventing technologies but tailoring them for the local area. For example, developing biodigesters suited for different climates, determining the best agricultural use of digestate such as for crops or pastures, and adjusting business models to fit local energy markets.

PRACTICAL EXAMPLE

The same biodigestion technology was tested across three regions in Brazil.

- **South:** marked presence of cooperatives, skilled producers, and cold winters. The biodigester operated efficiently but needed extra heating to keep production stable.
- **Midwest:** large cattle feedlots and pig farms, favorable logistics, and strong demand for agricultural energy. Biogas proved to be highly cost-effective.
- **North:** hot and humid climate, longer distances, and less infrastructure. The main challenge was to valorize digestate and gain farmer acceptance, which required training and technical support.

KEY MESSAGE

Solutions that are not customized for the area become expensive, less accepted, or abandoned. Local adaptation improves legitimacy, adoption, and long-term success of environmental and economic outcomes.

Lessons for replication

1. Assess climate before system design: biodigesters in cold regions need insulation or heating; in hot climates, costs are usually lower.

2. Consider herd type and size: pigs, cattle, and poultry produce manure with different volumes and characteristics. Therefore, it is important to select the right technological approach.

3. Adapt to available infrastructure: areas with energy, roads, and cooperatives can implement more complex systems; in isolated areas, use simplified solutions.

4. Align business models with local energy markets: in areas with high or unstable electricity costs, focus on on-site power generation; near urban centers, upgrade to biomethane.

5. Include social and cultural factors: assess acceptance of digestate use and promote training to reduce resistance.

6. Value affordable solutions for smallholders: simplified models help include family farms and promote social adoption.

5.2 How do you choose TRUs?

The next step is to set clear criteria for choosing which farms can be designated as representative TRUs. The selection must ensure these units accurately mirror the conditions of many other farms and serve as a reliable basis for technical validation, investor confidence, and knowledge sharing.

What makes a good TRU?

A representative Reference Unit (URT) should reflect the conditions of several other farms. A few criteria can guide the selection process:

- **Biosecurity:** farms must adopt appropriate hygiene and management practices to prevent manure from posing health or environmental risks.
- **Access to information:** it must be possible to collect and share clear data on costs, energy production, and biofertilizer use.
- **Regional diversity:** TRUs should be distributed across different climates and regions, since what works in the South may require adjustments in the North and vice versa.

- **Technology in practice:** the unit must demonstrate innovative and effective solutions, whether in biodigestion, composting, or water reuse.
- **Full-cycle utilization:** digestate should be used as a biofertilizer to close the nutrient cycle.
- **Social inclusion:** when TRUs involve smallholders, women, and youth, they gain social legitimacy and encourage more producers to adopt the technology.

PRACTICAL EXAMPLE

The project supporting this guide created a continuous process for selecting TRUs in Brazilian regions with intensive livestock farming at various scales.

- **Smallholders:** cost-effective biodigesters for herds of up to 30 cows, providing thermal energy for cooking and milking areas.
- **Large farms and cooperatives:** more resilient systems capable of generating electricity, producing biomethane, and supplying biofertilizers at scale.

This diversity is strategic because it shows that viable solutions exist for both family farming and large-scale agribusiness.

KEY MESSAGE

Representativeness forms the foundation of TRU's success. Thoughtful selection fosters social and political confidence, boosts adoption, and encourages replication.

Lessons for replication

1. **Start with small, representative farms:** select farms that exemplify the region to simplify identification and replication.

2. **Show results clearly:** record and communicate straightforward data, such as energy savings or fertilizer production, in simple-to-understand metrics.

3. **Ensure regional and scale diversity:** establish TRUs in different climates and at various production sizes to showcase adaptability.

4. **Value social inclusion** by integrating small farmers, women, and youth to enhance legitimacy, acceptance, and replication.

5. **Connect to public policies:** use TRUs as solid evidence to support credit lines, subsidies, and incentive programs.

5.3 How do TRUs assist with scalability and knowledge sharing?

Once established, TRUs play a vital role in diffusion and scalability by translating technical results into clear examples that reduce uncertainty and engage producers and investors. More than just testing equipment, TRUs demonstrate practical outcomes that can be replicated elsewhere.

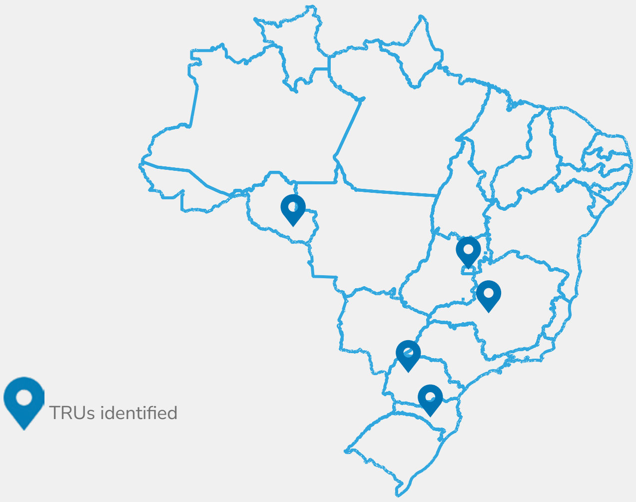
What role do TRUs play in the dissemination process?

- **Teach by example:** producers learn more effectively when they see other producers using the technology.
- **Reduce uncertainty:** investors and governments feel more confident when actual results are available, not just projections.
- **Expand outreach**: communication materials (videos, virtual tours, infographics) amplify impact beyond on-site visitors.
- **Build social trust:** tangible benefits such as energy savings, odor reduction, or increased agricultural productivity from digestate enhance social acceptance.

PRACTICAL EXAMPLE

The project's TRUs were used both to generate technical data and as communication tools. In some regions, institutional visits with policymakers, researchers, and cooperatives demonstrated biogas electricity production and digestate fertilization. Meanwhile, videos and illustrated reports expanded outreach, reaching thousands of people. Currently, the project identified five TRUs and has three more under assessment (see Figure 14).

Figure 14. **Location of TRUs considered in the Brazilian context**



This type of visibility enhances impact: a well-documented TRU can inspire dozens of producers, influence regional policies, and become even more effective when combined with communication and governance strategies.

- **Communication:** present technical results as clear, relatable messages.
- **Governance:** engage cooperatives, associations, extension services, and local governments to foster an environment that promotes diffusion.

KEY MESSAGE

TRUs serve as tools for scalability. By connecting knowledge, communication, and public policies, they enhance sustainable solutions across different contexts.

Lessons for replication

1. **Transform results into stories:** by moving beyond technical reports and highlighting practical examples of cost savings or productivity increases.

2. **Use accessible formats:** like videos, virtual tours, manuals, and posts to broaden outreach.

3. **Create engaging learning experiences:** field days and hands-on training are more effective than just reading or lectures.

4. **Engage with cooperatives and governments:** integrate TRUs into public policies and credit programs to boost impact.

5. **Present simple, tangible metrics:** replace technical units with straightforward equivalents like “energy for 50 homes.”

6. **Value the diversity of profiles:** keep TRUs across various sizes and settings (smallholders, cooperatives, agribusiness).

BOX 5 BEYOND TRUs: SOCIAL TECHNOLOGIES

While URTs and large farms are essential to validate and demonstrate technological solutions, family farming also requires strategies adapted to its economic, social, and productive reality. In this context, social technologies[14] represent inclusive and effective pathways to expand methane (CH_4) mitigation and sustainable manure management.

Example – Brushland Biodigester (biodigestor sertanejo):

- *Developed by Diaconia[15], inspired by Indian models.*
- *Built with affordable materials and regional techniques.*
- *Movable dome for biogas storage.*
- *Operated by rural families with basic training.*
- *Requires low maintenance and generates energy autonomy.*

Unlike technologies focused on maximum efficiency, the emphasis here is on ***reducing costs*** *and* ***improving the quality of life*** *for vulnerable families. Even with modest unit impacts,* ***large-scale replication*** *can generate significant social, environmental, and economic effects, especially in regions dominated by family farming.*

MAIN TAKEAWAY

Social technologies, such as the Brushland Biodigester, demonstrate that environmental sustainability can be aligned with social justice and community leadership, strengthening both methane mitigation and inclusive production.

14 Social technologies have the following key characteristics: i) a focus on socially and economically vulnerable groups, generating employment, income, and sustainable development; ii) active participation of users in the development process; iii) replicability with low economic and environmental requirements; iv) economic, social, cultural, and environmental sustainability. [59].

15 https://i17.eco.br/wp-content/uploads/2022/11/RT05-2022.pdf

5.4 Strategies and adaptations applicable in various contexts

Experience shows that establishing TRUs depends as much on specific productive contexts as on the consistency of procedures used to select, compare, and validate reference sites. Instead of seeking a single model, the goal is to prioritize replicable principles tailored to local realities. This approach ensures comparability between regions and countries while maintaining the flexibility needed for adaptations. Table 8 offers a summary of the advantages, limitations, and recommendations.

Table 8. **Advantages, limitations, and recommendations for TRU replicability**

ADVANTAGES	LIMITATIONS	RECOMMENDATIONS
Generates reliable technical data for public policies and investments.	Requires adequate monitoring and recording infrastructure.	Standardize data collection protocols and promote public transparency.
Strengthens communication and visibility of the technology.	Demands resources for materials and dissemination.	Produce videos, illustrated reports, and virtual tours.
Promotes integration between producers, investors, and researchers.	Involves costs and logistics for institutional visits.	Organize field days and events with cooperatives and associations.
Expands impact and inspires new producers and investors.	Depends on proper documentation quality.	Document practical cases with simple, tangible indicators.
Builds social trust by showing practical benefits (energy, soil fertility, odor reduction).	May face local cultural resistance.	Connect results to direct improvements in farmers' daily lives.

CONTINUED

ADVANTAGES	LIMITATIONS	RECOMMENDATIONS
Serves as a scalability and knowledge diffusion instrument.	Risk of low uptake if poorly communicated.	Translate technical results into clear, accessible messages.
Values social inclusion (family farmers, women, youth).	Requires additional social mobilization efforts.	Integrate with rural extension policies and inclusive credit programs.
Serves as a bridge between theory and practice.	May lose representativeness if poorly chosen.	Select farms typical of the region with diverse profiles.
Strengthens sectoral governance through cooperatives, associations, governments.	Risk of fragmented efforts without cooperation.	Create steering committees and inter-institutional agreements.
Demonstrates social technologies (e.g., sertanejo biodigester).	Limited individual impact compared to large projects.	Promote large-scale replication with participatory methods.
Improves quality of life for vulnerable families (clean energy, public health).	Depends on basic training and initial support.	Provide simple training and community follow-up.

International examples:

- **Costa Rica:** collaborative projects enhanced biodigestion, building trust among small and medium farmers [44].
- **China:** thousands of family-scale biodigesters installed in rural areas, adapted for cold climates (insulation) and tropical regions (low-cost models) [45].
- **United States:** AgSTAR demonstration projects established model farms with large-scale digesters and co-digestion, supporting training, economic analysis, and replication [46].

KEY MESSAGE

TRUs are versatile tools. When adapted to different climates, scales, and production systems, they act as bridges between technical innovation and public policy.

Lessons for replication

1. **Adapt technologies to the local context:** avoid copying models from other countries without making climatic, productive, and institutional adjustments.

2. **Select representative farms for TRUs:** pick sites that reflect current conditions to improve replication potential.

3. **Establish clear selection criteria:** biosecurity, data monitoring capacity, and economic viability are essential prerequisites.

4. **Ensure diversity in scales and profiles:** include small, medium, and large farms across various climates to demonstrate applicability.

5. **Value social inclusion:** involve family farmers, women, and youth to enhance legitimacy and social impact.

6. **Incorporate TRUs into public policies:** use generated evidence to support green credit, subsidies, certifications, and national mitigation programs.

✔ Checklist for Chapter 5

☐	**Adapting technologies to the local area**	Boosts efficiency and social acceptance.
☐	**Select representative TRUs**	Produces evidence relevant to producers with similar profiles and conditions.
☐	**Present results clearly and practically**	Encourages the involvement of producers, investors, and governments.
☐	**Valuing diverse profiles and contexts**	Supports the replicability of solutions across different regions and scales.
☐	**Integrating social inclusion**	Enhances legitimacy and increases adoption among family farmers, women, and youth.
☐	**Link TRUs to public policies and green credit**	Transform local experiences into national mitigation programs and investments.

6 DIAGNOSING OBSTACLES TO ADOPTING MITIGATION TECHNOLOGIES

The widespread adoption of emission reduction technologies such as biodigestion involves more than just technical considerations or economic feasibility. In various settings, proven solutions are often underutilized because institutional, financial, social, or regulatory barriers prevent their implementation or hinder their scale-up.

Proceeding with technology dissemination without first identifying the existing obstacles can weaken the entire political, institutional, and financial effort. Scaling up solutions without proper diagnosis introduces clear risks: low farmer adoption, equipment abandonment in the field, underused installed structures, misallocated investments, wasted public resources, and even widespread distrust in the effectiveness of policies. Barriers to boosting the energy recovery from livestock manure are both structural and systemic.

- **Structural barriers** include a lack of infrastructure, poorly designed public policies, the absence of incentives, or insufficient funding.
- **Systemic barriers** include coordination failures among actors, gaps in technical knowledge, limited extension services, and weak integration of value chains.

These elements, whether alone or combined, weaken the economic, social, and institutional viability of biodigestion and limit its ability to generate renewable energy, replace synthetic fertilizers, and decrease CH_4 emissions.

Therefore, **identifying barriers** must be a key part of any mitigation plan. It helps recognize which obstacles are most significant, how they appear in different productive settings, and how they can be addressed through public policies, incentive tools, and training initiatives.

KEY MESSAGE

No technological progress happens without first understanding and tackling the barriers that block its adoption. Finding structural and systemic obstacles is essential to turning technical potential into long-term, practical, acceptable, and sustainable mitigation programs.

6.1 Why are studying barriers so important?

Studying barriers serves as a bridge between technical diagnostics and practical implementation. It makes sure that estimates of energy potential or technology reference models can be turned into real results, customized to each country's institutional and industrial conditions. Adding this step increases the chance that solutions will scale up and stay relevant, rather than just remaining as isolated pilots.

Barrier diagnosis also encourages dialogue among stakeholders — producers, technicians, policymakers, and financial institutions — ensuring solutions are developed cooperatively and tailored to local realities.

Barriers can occur at different levels:

- **Technical:** issues related to technology, operation, and specialized knowledge. Examples include a lack of project designs suited for small and medium farms (mostly focused on large-scale farms), challenges in maintenance and operation, the absence of regional technical support, and the poor quality of locally available equipment or spare parts.
- **Financial:** economic barriers that prevent initial investment or system sustainability from being feasible. Examples include high implementation costs for small and medium-sized farms, limited access to targeted rural credit, financing lines with excessive bureaucracy or unrealistic collateral requirements, and difficulties in monetizing benefits such as biogas, biofertilizers, and carbon credits.
- **Institutional and regulatory:** challenges related to the legal, normative, and governance framework. Examples include a lack of stable, coordinated public policies; fragmented environmental regulations across states; the absence of official recognition for biofertilizers as equivalent to synthetic fertilizers; and fragmentation among states, with limited integration among environmental agencies, the energy sector, and cooperatives.
- **Social and cultural barriers:** related to perception, acceptance, and community practices. Examples include resistance to adopting new technologies due to perceived risks, a lack of cultural recognition of manure as an energy and fertilizer resource, distrust regarding the economic viability of small-scale biodigestion, and a weak collective organization of producers to support centralized or cooperative plants.

By recognizing barriers, it becomes possible to:

- Base public policies on evidence by guiding financial incentives, training programs, and regulatory frameworks to address the sector's actual needs.
- Lower investment risks and offer greater predictability to banks, cooperatives, and companies that finance or operate biodigesters.
- Encourage successful technology adoption by tailoring solutions to producer size, production methods, and regional conditions.
- Maximize environmental and economic benefits, including renewable energy production, partial fertilizer replacement, and methane reduction.

KEY MESSAGE

Including barrier diagnosis in technical and economic planning increases solution replication, improves public policy compliance, and builds stakeholder trust.

Lessons for replication

1. **Include barrier diagnosis as a necessary step:** mapping potential alone isn't enough; it's essential to identify obstacles to large-scale adoption.

2. **Classify barriers into technical, financial, institutional, and social categories:** this structure helps compare across countries and set priorities.

3. **Use participatory methods:** involving farmers, cooperatives, and local institutions enhances legitimacy and reveals barriers not seen in purely technical studies.

4. **Customize the analysis for the Global South:** consider challenges such as limited rural credit, informal production, weak extension services, and fragile regulatory frameworks.

5. **Turn barriers into an action plan:** each obstacle identified should be matched with specific actions, like training, credit, regulatory changes, or social communication.

6. **Update regularly:** barriers change over time; re-evaluating the diagnosis helps prevent outdated policies or ineffective incentives.

6.2 How do you perform a barrier study?

Barrier studies can follow different paths, varying in complexity and required resources. The choice of method should balance scientific rigor with practical relevance, ensuring that results effectively guide public policies and investments.

Common methodological options include:

- **Quantitative studies** are valuable for assessing perceptions across numerous stakeholders, enabling regional or sectoral comparisons. Structured surveys remain the most common method.
- **Structured surveys** are the most common tool, often using Likert-type scales—a series of statements rated on a scale, e.g., from “strongly disagree” to “strongly agree”—to measure attitudes, knowledge, perceptions, and behavioral change.
- **Qualitative studies** help explore underlying factors, such as social perceptions, institutional structures, or coordination issues. Common methods include participatory workshops and focus groups.

- **Mixed approaches** integrate quantitative and qualitative elements to grasp both scale and context. They are especially important in the Global South, as they deliver reliable, comparable, and flexible results.
- **Case studies** allow in-depth analysis of farms or projects that have adopted or attempted to adopt biodigesters, emphasizing real-world challenges.
- **Literature review** and benchmarking serve as valuable starting points when data is limited, helping to identify common barriers and proven solutions.
- **Multicriteria methods** (e.g., Delphi Study, Analytic Hierarchy Process – AHP) are formal techniques used to organize expert judgments and transparently rank key factors.

Table 9 gives an overview of the most commonly used methodologies in agricultural barrier studies, including their descriptions, key features, and relevant references.

Table 9. **Main methodologies for barrier studies**

METHODOLOGY	APPROACH	DESCRIPTION	MAIN CHARACTERISTICS
Surveys (structured questionnaires)	Quantitative	Application of standardized questionnaires to farmers, technicians, or policymakers.	Produces numerical data; allows statistical analysis and regional comparison; useful for identifying adoption patterns.
Focus groups and participatory workshops	Qualitative	Organized meetings with multiple stakeholders to identify, discuss, and prioritize barriers.	Capture diverse perceptions; encourage dialogue and consensus-building; adaptable to different contexts.
Multicriteria methods (Delphi, AHP)	Quantitative/ Qualitative	Formal techniques structuring expert judgments and ranking critical factors.	Organize complex variables; allow transparent prioritization; applicable to policy processes.
Literature review and benchmarking	Qualitative	Review of studies, experiences, and policies from other regions or countries.	Identifies recurring barriers and tested solutions; useful as a starting point in low-data contexts.
Mixed approaches	Mixed	Integration of quantitative and qualitative methods in one study.	Balances depth and representativeness; increases robustness; recommended for replicable policy support.
Case studies	Qualitative	Detailed analysis of projects or farms implementing biodigesters.	Identifies practical barriers in real-life conditions.

Source: [47]; [48]; [49]; [50]; [51].

PRACTICAL EXAMPLE

Instituto 17 (i17) applied this approach in 2021 and 2024 barrier studies on biodigestion. This allowed for comparison over time and the identification of changes in barrier importance.

The results of this perception study are available through the referenced link.

The methodology consisted of five sequential steps:

1. **Documentary research**
   - Review of literature, technical reports, regulations, and market studies.
   - Initial identification of barriers and co-benefits.
2. **Technical analysis with experts**
   - Consultations with strategic agencies;
   - Refining barriers within the Brazilian context.
3. **Consultation with key sector stakeholders**
   - Interviews with experts, consultants, and biogas companies, including field-level perspectives.
4. **Sectoral survey**
   - Online questionnaire targeting professionals with direct experience in waste management and biodigestion, focusing on identifying key barriers and emerging trends.

Experience has demonstrated that understanding both the benefits and limitations of a barrier assessment is essential. Only then can the results be used strategically to guide policies and investments without creating unrealistic expectations, while allowing for regional adaptation.

KEY MESSAGE

Barrier studies are effective only when they combine rigorous methodology with practical relevance, producing reliable evidence to guide policy and investments that can be adapted to realities in the Global South.

Lessons for replication

1. **Adapt methodology to local capacity:** in data-scarce contexts, simple methods like focus groups and benchmarking already provide valuable evidence; in data-rich contexts, national surveys improve representativeness.

2. **Include diverse stakeholders:** farmers, technicians, policymakers, and financial institutions recognize unique and complementary barriers.

3. **Prioritize critical obstacles:** rank results to highlight which barriers should be addressed first.

4. **Transform diagnostics into practical tools:** convert findings into credit lines, training programs, regulatory incentives, or institutional support.

5. **Ensure comparability:** use methods that support temporal or cross-country analysis to enhance replicability.

6.3 Strategies and adaptations in different contexts

Barrier diagnosis identifies obstacles, their locations, and the conditions under which they hinder the adoption of manure management technologies by analyzing technical, economic, regulatory, and sociocultural evidence. It is more than just a one-time survey; it organizes information to guide policies, financing, and capacity building, focusing on measurable mitigation and adaptation outcomes.

Table 10 provides an overview of the main advantages, limitations, and key insights for replicability in barrier studies

Table 10. **Advantages, limitations, and recommendations for replicating barrier studies**

ADVANTAGES	RECOMMENDATIONS
Identify technical, economic, institutional, and cultural barriers that limit diffusion.	Require methodological adaptation to regional specificities.
Help define where and how to intervene effectively (training, credit, technological development).	Prioritization varies with market maturity and local policies.
Support program design, incentives, and financing mechanisms based on evidence.	Effectiveness depends on government openness and institutional capacity.
Stimulate dialogue among farmers, public institutions, financial agents, and technology providers.	Require active multi-stakeholder forums for continuity.
Identify gaps preventing large-scale adoption and guide solutions.	Impact depends on innovation ecosystems and actor integration.

LIMITATIONS	RECOMMENDATIONS
Barriers vary across regions and systems, limiting generalization.	Customize methodologies; avoid simplistic extrapolations.
Policy and market shifts require periodic revision.	Institutionalize continuous monitoring, not just ad hoc studies.
Many barriers reported subjectively, reducing analytical robustness.	Combine qualitative and quantitative methods for reliability.
Risk of low effectiveness if results are not integrated into policy.	Link diagnostics to sectoral plans, policies, and concrete financing.
Bureaucratic hurdles and weak inter-agency coordination hinder barrier removal.	Map key actors early and design participatory governance strategies.

International examples:

- **Kenya:** performed a literature review, conducted an expert survey, and applied the AHP method to rank barriers across five categories: financial, technical, institutional, informational, and infrastructural [52].
- **India:** compared rural and urban systems through a literature review, semi-structured interviews, and logical analysis, categorizing barriers into six groups: financial, market, social, regulatory, technical, and informational [53].
- **Global study:** a systematic review identified barriers to large-scale biogas implementation in both developed and developing countries, focusing on six categories: technical, economic, market, institutional, sociocultural, and environmental [54].
- **Colombia:** a mixed approach combining literature review, case studies, and qualitative analysis identified financial, technological, social, institutional, and R&D barriers [55].

These examples demonstrate that although barriers vary in type and intensity, common patterns can inform policy decisions. Therefore, there is a need for coordinated strategies, involving multiple stakeholders, and ongoing refinement of analytical frameworks.

KEY MESSAGE

Barrier diagnostics are only effective when translated into specific action plans. Tailoring methods to match each country's institutional and social capabilities ensures greater impact and easier replication.

Lessons for replication

1. Adapt the methodology to the local context: avoid copying ready-made studies; customize it to local agricultural, climate, and institutional conditions.

2. Combine qualitative and quantitative methods: surveys, interviews, and participatory workshops improve robustness and comparability.

3. Turn barriers into practical solutions: develop policies, incentives, or training programs for each obstacle.

4. Include multiple social actors: farmers, cooperatives, governments, banks, and civil society, to provide diverse perspectives.

5. Promote social and gender inclusion: ensure family farmers, women, and youth have access to credit, training, and value chains.

6. Ensure regular updates: barriers evolve with policies, markets, and technologies; consistent review cycles prevent obsolescence.

Checklist for Chapter 6

☐	**Map barriers before investing**	Help avoid wasted resources and unviable projects.
☐	**Classify obstacles into categories (such as technical, financial, institutional, social)**	Guide targeted solutions and facilitate policy planning.
☐	**Use methodologies suited to local capacity, such as surveys, workshops, or case studies)**	Ensure reliable diagnostics even in data-scarce contexts..
☐	**Involving multiple stakeholders (farmers, technicians, governments, banks, civil society)**	Enhance legitimacy and improve the quality of results.
☐	**Turn barriers into actionable plans**	Transform diagnostics into practical mitigation measures linked to policies, credit, and training.
☐	**Promote social and gender inclusion**	Ensure access for family farmers, women, and youth.
☐	**Regularly update diagnoses**	Keep policies and programs aligned with changing markets, technologies, and climate conditions.

7

PROMOTING GENDER EQUALITY AND SOCIAL INCLUSION (GESI)

Mitigating CH_4 in the livestock sector is not just a technical or economic challenge; it is also a social process that affects men, women, youth, family farmers, Indigenous peoples, and traditional communities in many ways.

Especially in the Global South, livestock systems support millions of families within different cultural and institutional settings. Therefore, incorporating gender equality and social inclusion (GESI) is essential for manure management solutions to be effective, legitimate, and scalable.Inequalities in access to resources, knowledge, and decision-making power directly affect the adoption of mitigation technologies. In many areas, women are responsible for daily animal care and using by-products like biofertilizers, yet they often lack access to credit, training, or land ownership. Similarly, rural youth could play a key role in adopting innovations, but they face institutional barriers or limited income opportunities. Ignoring these social factors weakens the effectiveness of climate policies and risks worsening existing inequalities.

On the other hand, when projects integrate GESI from the start, the advantages grow.

- Higher adoption rates because diverse groups feel represented and engaged.
- Improved social and economic resilience by diversifying income sources and reducing vulnerabilities.
- Greater political legitimacy and recognition gain stronger support from local communities and international financiers.
- Inclusive solutions with wider and more enduring climate impacts tend to be more sustainable and easier to replicate.

The challenge is understanding that there isn't a single model for gender and social inclusion. Each country, region, and community has its own norms, values, and institutions. Instead of relying on ready-made formulas, participatory approaches that respect local cultures and socioeconomic realities are essential. This guide provides principles, examples, and tools to demonstrate how GESI can be incorporated into diagnostics, projects, and public policies aimed at methane mitigation.

KEY MESSAGE

Including GESI in livestock methane reduction is not only about fairness but also a strategic way to increase technology adoption, generate social benefits, and ensure solutions are credible, repeatable, and sustainable.

7.1 Why include gender and social inclusion in methane mitigation projects?

Livestock CH_4 mitigation projects are often approached solely from a technical perspective, emphasizing technology design, emission reduction calculations, and economic feasibility. However, international and Brazilian experience demonstrates **that successful implementation heavily relies on social factors**. Overlooking gender and social inequalities risks developing policies that are technologically advanced but socially unworkable.

In many rural communities of the Global South, the work of women, youth, and family farmers is vital for daily animal care, facility cleaning, and by-product reuse like biofertilizers. However, these groups often encounter barriers such as:

- **Unequal access to credit and finance:** women and family farmers often lack land titles or formal guarantees, which restricts their ability to obtain green credit.
- **Limited technical training:** training programs usually focus on large-scale producers, excluding smallholders and rural youth.
- **Low representation in decision-making bodies:** cooperatives and producer associations are often led by men.
- **Cultural and institutional constraints:** gender norms and local customs may limit women's and youth's involvement in productive or decision-making activities.

When these aspects are ignored, technologies like biodigesters, composting, or collective manure management may be overlooked or not fully used. In contrast, projects that include GESI from the start achieve:

- **Promote wider adoption** by involving various producer profiles.
- **Economic empowerment** through access to credit, training, and new markets.
- **Broader inclusion enhances social and climate resilience**, broadening strategies and strengthening long-term adaptation.
- **Creates alignment with global goals**, particularly SDG 5 (Gender Equality) and SDG 10 (Reduced Inequalities).

These benefits are clearly visible in practice. For example, in Brazil, women's networks in the biogas sector have fostered technological innovation and community training; low-cost biodigester programs have been customized for family farms; and rural credit policies are increasingly including social inclusion criteria.

To assess the level of integration, projects can be classified using the UK PACT GESI scale [56]:

- **GESI-blind:** completely overlooks inequalities.
- **GESI-neutral:** recognizes inequalities but does not intervene.
- **GESI-sensitive or responsive:** addresses the practical needs of marginalized groups, disaggregates data by gender and other identifiers, and provides support.
- **GESI-transformative:** aims to change norms, power structures, and cultural values, redistribute resources, and empower marginalized groups.

Projects should aim to move beyond “blind” or “neutral” approaches toward “sensitive” and ultimately “transformative” strategies.

PRACTICAL EXAMPLE

In Brazil, the Brushland Biodigester (Biodigestor Sertanejo), designed for semi-arid regions, has helped families reduce cooking gas expenses, improve food security, and increase economic independence [57]. Likewise, the low-cost biodigester has empowered women farmers by decreasing household chores and their dependence on traditional fuels [58].

BOX 6	**LOW-COST BIODIGESTER**

A smallholder in Santa Catarina (southern Brazil) installed a low-cost biodigester with technical support from EPAGRI[16] to manage manure from 30 cows. The investment paid off in just 18 months. Biogas is now used for cooking and water heating, while the system requires minimal maintenance. Benefits include:

- *Energy and cost savings.*
- *Easier daily work, especially for women.*
- *Improved quality of life and autonomy.*

"I loved it, because it reduced my work a lot. The stove is cleaner, there's less smoke, no need to heat water for dishes and milking. I even have more time to join women's clubs and courses. I'm very happy." (Zenilde Luiz, April 2025).

MAIN TAKE AWAY

Accessible technologies like low-cost biodigester deliver strong environmental, economic, and social impacts, while advancing gender equality in rural communities.

KEY MESSAGE

Incorporating GESI into CH_4 mitigation projects guarantees that technical solutions are socially acceptable, promotes adoption, enhances community resilience, and aligns with global commitments on climate justice and sustainable development.

[16] Epagri (Santa Catarina State Agricultural Research and Rural Extension Company) — a public company that promotes agricultural research, rural development, and technical assistance to farmers in the state of Santa Catarina, Brazil.

Lessons for replication

1. Integrate GESI from the start: considering gender inequalities and social inclusion in the diagnosis helps prevent exclusionary solutions.

2. Value diverse and productive roles: recognize that women, youth, and family farmers are already involved in manure management and can be key agents of the transition.

3. Create specific incentives: credit lines, training, and support policies tailored to marginalized groups increase technology adoption.

4. Adapt to local culture: respect each community's norms, values, and institutions to ensure true and voluntary inclusion.

5. Monitor social outcomes: in addition to environmental and economic indicators, track whether projects are decreasing inequalities and boosting social participation.

7.2 How can teams be prepared to incorporate GESI?

Experience shows that the makeup and **preparation of teams** are essential for ensuring that the integration of Gender Equality and Social Inclusion (GESI) stays consistent in CH_4 mitigation policies and projects. A diverse, aware, and committed team broadens perspectives and improves strategy development, preventing GESI integration from becoming just a formal statement. When diversity exists within the team, it fosters a more supportive environment for turning inequalities into real practices.

Diverse teams also ensure that GESI mainstreaming remains **ongoing and integrated** within institutions, rather than being a standalone step or dependent on only a few sensitized individuals. This reduces the risk of setbacks and enhances the ability to implement structural changes.

Team commitment depends on two complementary factors:

- **Being sensitive to the GESI** issue means understanding the importance of gender equality and social inclusion as essential factors for project success.

- **Translate practical knowledge** into tools, methods, and experiences that show how to include these aspects at every phase of the project cycle.

To evaluate these aspects, self-assessment questionnaires or discussion sessions can be utilized. Examples of questions that help measure the level of readiness include:

- How do team members perceive the significance of including GESI in the project?
- What is the latest understanding of inclusion strategies and tools?
- What is the level of interest in participating in specific trainings?
- Is there gender equity and diversity in team composition and decision-making processes?

These questions can also be expanded to include partner institutions involved in implementation, thereby strengthening GESI integration at all stages and among all actors.

PRACTICAL EXAMPLE

In Brazil, under the ABC+ Plan, a self-assessment questionnaire was given to participants of the State Management Groups. The responses showed awareness of the importance of integrating GESI but also revealed gaps in technical knowledge about practical tools. At the same time, there was strong interest in participating in specific trainings. These results helped guide the implementation of an initial awareness-raising workshop and the development of targeted capacity-building sessions for those eager to deepen their understanding. The process strengthened the foundation for more effective integration of GESI into state-level plans, demonstrating that well-conducted diagnostics can lead to real actions for capacity-building and institutional change.

KEY MESSAGE

Diverse, aware, and trained teams are the foundation for more inclusive policies and projects. Without this base, GESI integration often remains superficial. With it, opportunities arise for structural changes that can reshape how gender and social inequalities are recognized and addressed in climate initiatives.

Lessons for replication

1. Value diversity within teams: encourage equal participation regardless of gender, race, age, and socioeconomic background, reflecting the communities served.

2. Turn diagnostics into action: use assessment and questionnaire results to guide trainings, workshops, and practical inclusion strategies.

3. Invest in progressive capacity-building: start with awareness-raising workshops to align understanding and move toward targeted training sessions with tools relevant to the project's context.

4. Broaden the commitment beyond the team: by involving partner institutions in the same assessment and training approach, ensuring that GESI integration is cross-cutting and collective.

7.3 What are the steps to integrate GESI into mitigation projects?

The integration of GESI in CH_4 mitigation projects should be seen as an ongoing process rather than a one-time step. It begins with understanding the context, guides project design, and continues through monitoring and evaluation. When executed effectively, this approach makes solutions more resilient, legitimate, and sustainable over the long term.

To ensure effectiveness, it is advised to follow a **series of connected steps:**

- **Context diagnosis:** Conduct a gender and social inclusion analysis to identify inequalities, access barriers, opportunities, and potential impacts on women, youth, traditional communities, and other underrepresented groups.
  - Use secondary data and participatory methods like focus groups, surveys, interviews, or dialogues with representative organizations.
  - Assess the project team's understanding and technical skills in GESI.
  - The analysis should produce clear recommendations and affirmative actions to decrease barriers, increase positive impacts, and enhance team capacity.
- **Project design:** Incorporate the analysis results from the initial formulation, making sure that goals, indicators, and activities include GESI dimensions throughout all aspects.

- **Resource allocation:** Ensure adequate budgets and resources for the successful implementation of GESI strategies. Without dedicated financial and human support, integration often diminishes.
- **Implementation:** Foster multisectoral and multidisciplinary partnerships, including organizations representing underrepresented groups. This is also the time to strengthen awareness-raising and capacity-building efforts among teams with less experience in GESI.
- **Monitoring and evaluation:** Use participatory tools that encourage active listening from beneficiary populations. Gather and analyze data disaggregated by gender, race, age, and other social markers to identify bottlenecks, adjust strategies, and transparently measure impacts.

There are many reference materials that support GESI mainstreaming in projects. This variety allows methodologies to be customized to the specific context.

- **Integrating Inclusion into Climate Action** *(UK PACT):* draws on experiences from Latin America, Sub-Saharan Africa, and Asia to identify effective practices, common challenges, and lessons learned.
- **How to Integrate Gender into Climate-Smart Agriculture Projects** *(FAO and World Bank):* provides theoretical and practical guidance, checklists, and case studies.
- **Gender Mainstreaming:** A Question of Human Rights (Luxembourg Aid & Development, UN Women): Although not focused on climate, it provides a practical guide for incorporating gender equity into various initiatives, promoting a structured approach at every project stage.

While useful, these guides need adjustment to local contexts, taking into account the cultures, norms, and institutional structures of each country.

PRACTICAL EXAMPLE

Instituto 17 (i17) conducted a gender and social inclusion diagnosis to support the integration of GESI into biogas value chain projects in Brazil. Since no systematized data was available, records from the National Classification of Economic Activities (CNAE)[17] and the Annual Social Information Report (RAIS)[18] were used to map companies in the sector and their workforce. Results showed that women hold only 21% of jobs in the chain, earn lower wages at all levels, and face even greater inequalities when they are Black or Brown, being concentrated in lower-paying positions. Based on this evidence, recommendations were developed to address structural inequalities and build a fairer, more resilient biogas sector.

KEY MESSAGE

GESI integration is a continuous strategic effort, not a standalone action. Prioritizing equity in methane mitigation project cycles leads to more resilient solutions with lasting social impact.

Lessons for replication

1. **Focus on equity, not just mitigation:** recommend specific actions to ensure benefits such as credit, technology, and training are available to all social groups.

2. **Develop a comprehensive context diagnosis:** invest in robust GESI analyses to inform strategies and actions from the start.

3. **Present results with transparent data:** break down information by gender, race/ethnicity, age, and other social indicators to show progress and challenges.

4. **Forge strategic partnerships:** connect with networks, associations, and representative organizations of underrepresented groups to design and implement actions.

5. **Link to structural policies:** use local lessons to inform national and regional programs, broadening the impact of inclusive practices.

17 The CNAE is the Classificação Nacional de Atividades Econômicas (National Classification of Economic Activities), Brazil's official system for categorizing companies by sector and activity. Managed by the Brazilian Institute of Geography and Statistics (IBGE), it offers a standardized framework for taxation, regulation, and statistical analysis, and is widely used for mapping economic sectors and employment trends.

18 The RAIS is the Relação Anual de Informações Sociais (Annual Social Information Report), Brazil's mandatory survey conducted by the Brazilian Ministry of Labor that collects detailed data on formal employment contracts. It serves as a key source of labor statistics, supporting social and economic policies, monitoring compliance with labor laws, and informing research on employment trends.

BOX 7 WOMEN IN BIOGAS NETWORK (REDE MULHERES DO BIOGÁS)

*The **Women in Biogas Network** is a Brazilian initiative, created under the **Brazil Energy Programme (BEP)**, to promote gender **equity** in the biogas sector. The network is incubated at Instituto 17 and has become a space for connection, empowerment, and support for women, combining WhatsApp groups, meetings, online mentoring, and in-person events. Its mission is **to connect and empower women in the sector in pursuit of gender equality**, and its vision is to consolidate itself as a national reference in promoting equity in the energy transition.*

Highlights of the Women in Biogas Network:

- *Platform for coordination and mutual support, with **more than 500 members** in Brazil and abroad.*
- *Collaborative work with companies and strategic actors to foster **institutional best practices.***
- *Valuing principles such as justice, diversity, solidarity, collaborative leadership, and transparency.*
- *International recognition with the Hero of the Year award, granted by the World Biogas Association (WBA) in 2023.*
- *Consolidation as a strategic network **to give visibility to women professionals in the sector** and transform organizational structures toward inclusion and sustainability.*

Guided by its values and collaborative practices, the Network seeks not only to expand women's presence in the biogas sector but also to transform organizational structures, so they become fairer, more inclusive, and more sustainable.

MAIN TAKEAWAY

The Women in Biogas Network shows that social mobilization initiatives can make the energy transition more inclusive, connecting professionals, strengthening women's leadership, and driving structural changes in the bioenergy sector.

Checklist for Chapter 7

☐	**Map inequalities and social barriers in the initial diagnosis**	Ensure diverse groups are included from the start.
☐	**Classify the project's GESI level (blind, neutral, sensitive, transformative)**	Set achievable progress goals.
☐	**Add social indicators to the project's results framework**	Monitor inclusion alongside environmental outcomes.
☐	**Build diverse teams and utilize readiness assessments**	Ensure institutional capacity for GESI integration.
☐	**Investing in progressive training and participatory workshops**	Encourage ownership among actors.
☐	**Allocate dedicated budgets for GESI**	Prevent reliance on leftover resources.
☐	**Prioritize affordable, user-friendly social technologies**	Enhance replicability and impact.
☐	**Partner with representative networks and organizations**	Increase legitimacy and strengthen institutional ties (e.g., Brazilian Women Biogas Network).
☐	**Monitor results with disaggregated data (gender, race, age, etc.)**	Identify ongoing inequalities and refine strategies.
☐	**Connect local lessons with structural policies**	Incorporate inclusive practices into national and regional initiatives.

8 NEXT STEPS FOR REPLICATION

Throughout this guide, we follow a structured approach that moves from a global understanding of methane's role to practical solutions tailored to local needs. Each chapter aims to help policymakers, technicians, producers, and decision-makers turn diagnostics into tools for real climate actions. We begin by highlighting the global importance of livestock in methane emissions, then proceed with mapping value chains, projecting manure's territorial and energy impacts, selecting and customizing technologies, identifying barriers, and finally, including gender and social inclusion.

Reducing methane emissions presents an urgent opportunity. The Brazilian experience shows that it is possible to convert an environmental liability into energy, agricultural, and social benefits. When supported by reliable data, appropriate technologies, and consistent public policies, reducing animal manure emissions offers multiple advantages: it shortens the impact of global warming, improves food security, increases access to renewable energy, and promotes social inclusion.

More than just a technical manual, this guide encourages each country to develop its own methane mitigation strategy, using the framework provided here as a foundation. Replication does not mean copying; it involves **adjusting methodologies, criteria, and solutions to fit local contexts.** This approach helps align local actions with global commitments, such as the **Paris Agreement**, the **Sustainable Development Goals (SDGs)**, and the **Global**

Methane Pledge, thereby empowering countries in the Global South to become leaders in the shift toward low-carbon livestock.

Key messages from this guide:

- **Methane mitigation is strategic:** it reduces short-term global warming and offers social, economic, and environmental benefits.
- **Solid mapping is the first step:** understanding value chains and production systems ensures focus and efficiency.
- **Spatial data has an impact:** transforming diagnostics into regional insights helps shape effective public policies.
- **Technologies need to be adapted:** there is no one-size-fits-all solution, only approaches tailored to local contexts.
- **Barriers and social inclusion define the scope:** eliminating technical, financial, and institutional obstacles, and integrating GESI to ensure legitimacy and acceptance.

This guide ends with a call for collective action. The effort to reduce methane emissions from livestock isn't the responsibility of one country but a shared mission among nations with similar challenges, potential for productivity, and a desire to innovate. The Global South includes not only most of the world's population but also a wide range of agricultural systems and the social energy needed to create transformative solutions. By tailoring this roadmap to their specific circumstances, these countries can demonstrate that it is possible to achieve food security, social inclusion, and climate mitigation all at once.

The time to act is now; **it is up to the Global South to lead the way and show that switching to sustainable, fair, and low-carbon livestock is not only necessary but also achievable, effective, and inspiring for the entire planet.**

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APPENDICES

Glossary of Manure Management Systems

• **Anaerobic lagoon:** designed for the stabilization and storage of liquid manure, usually uncovered and with a retention time longer than one year. The treated water can be recycled for irrigation, fertigation, or other uses. Despite their simplicity, they are linked to high methane emissions if the lagoon is not covered or if the biogas is not properly flared or used.

• **Anaerobic digester:** enclosed units that facilitate anaerobic digestion of waste, producing biogas (CH_4+ CO_2) and digestate. When operated with proper gas capture and energy use, they offer high mitigation potential. They require adequate infrastructure, operational control, and safe management of the digestate. For anaerobic digestion to effectively reduce greenhouse gas (GHG) emissions, both biogas and digestate need to be managed efficiently. Practices such as open flaring (burning biogas without energy recovery) should be avoided, and systems must be continuously monitored to minimize fugitive emissions.

• **Solid storage:** a straightforward system where manure is piled outdoors for several months. Common on small farms, but it risks nutrient losses and greenhouse gas emissions from anaerobic fermentation inside the pile.

• **Pit storage:** manure is stored beneath facility floors, with minimal or no water added. Common in confinement systems but poses high emission risks if not managed with proper treatment.
• Liquid/slurry system: manure is stored in tanks or lagoons in liquid or semi-liquid form, with or without added water. Usually associated with later application to soil, it is common in intensive systems and needs careful management to prevent diffuse emissions.

• **Composting:** a biological process that occurs in the presence of oxygen, promoting controlled decomposition of organic matter. It stabilizes manure and produces organic compost, which can be used as agricultural fertilizer. Composting significantly reduces CH_4 and N_2O emissions compared to solid storage or uncovered piles. It can be applied to separated solids or directly to manure with a high C/N ratio.

• **Poultry manure without litter:** a system where manure collects dry in pits beneath cages. It is a passive type of composting and is commonly used in layer hen production.

• **Poultry manure with litter:** manure builds up on plant-based bedding such as wood shavings and straw. After 6–12 months, the material is collected and can be used as organic compost. Common in broiler production.

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