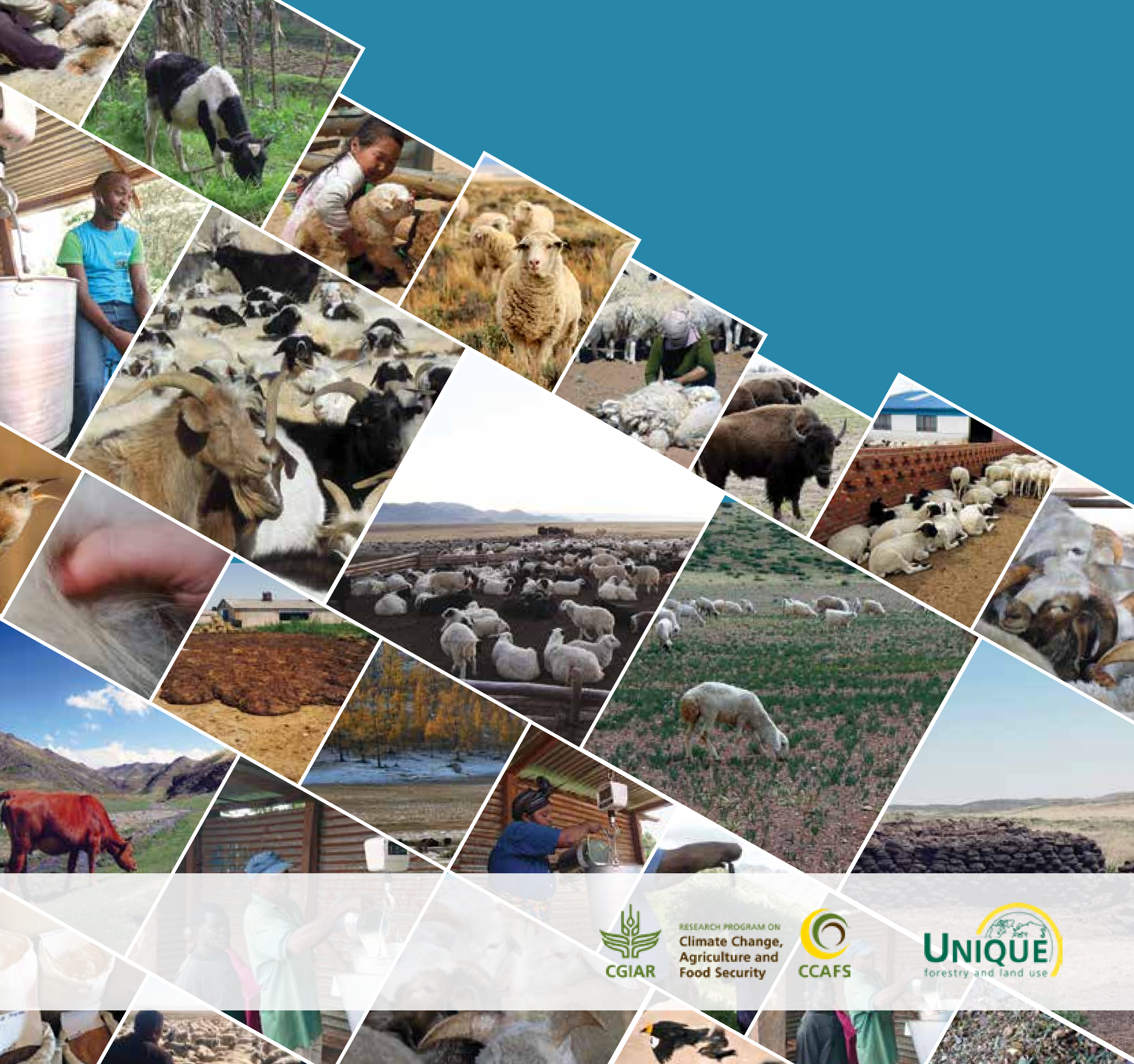
Food and Agriculture Organization of the United Nations

GLOBAL RESEARCH ALLIANCE ON AGRICULTURAL GREENHOUSE GASES

Livestock Activity Data Guidance (L-ADG)

Methods and guidance on compilation of activity data for Tier 2 livestock GHG inventories



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Wilkes, A. and van Dijk, S. (2018) Tier 2 inventory approaches in the livestock sector: a collection of agricultural greenhouse gas inventory practices. Available at: https://www.agmrv.org/wp-content/uploads/2018/11/Livestock-Tier-2-collection.pdf

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Methods and guidance on compilation of activity data for Tier 2 livestock GHG inventories

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About the Livestock Activity Data Guidance

Livestock emissions – including enteric fermentation, manure management and emissions from dung and urine deposited on pasture – account for about 11% of global greenhouse gas (GHG) emissions. To respond to the urgent threat of climate change, Parties to the Paris Agreement submitted Nationally Determined Contributions (NDCs). One way of tracking progress towards the NDCs is through national GHG inventories. GHG inventories play a key role in the transparency framework through which progress towards national and global climate goals will be tracked. A recent review found that among 140 developing countries, 92 have included livestock-related emissions in their NDCs, but very few have national GHG inventories that are capable of tracking changes in livestock emissions due to mitigation policies and measures. The main gap is that the vast majority of GHG inventories use the IPCC Tier 1 approach, which can only reflect change in livestock numbers. Tracking change in management and productivity requires a Tier 2 approach. The IPCC Tier 2 approach primarily uses activity data to estimate emissions. Lack of activity data and incomplete or poor quality data are commonly perceived barriers to using a Tier 2 approach.

The definition of activity data in this guidance: a note on terminology

The IPCC Guidelines explain that emissions from a GHG source are typically calculated as:

Emissions = Activity data × Emission factor

Activity data represent the extent to which a human activity takes place, and the emission factor represents GHG emissions per unit of activity. For example, in the Tier 1 approach for livestock emissions, the activity data is the population of each type of livestock and the default emission factor is an estimate of GHG emissions per head per year.

In the Tier 2 approach, the emission factor is estimated using data on performance (e.g. live weight, milk yield, wool production) and management (e.g. feed digestibility, manure management). These data also reflect human activity in the management of livestock. Therefore, these guidelines refer to both animal population data and animal performance or management data as 'activity data'. This usage is consistent with usage in Volume 4, Chapter 10 of the 2006 IPCC Guidelines on Livestock and Manure Management Emissions, which refers to feed characterisation as the collection of activity data.

However, these barriers may be more perceived than real. When first adopting a Tier 2 approach for livestock GHG emissions, there are few countries – including developed countries – where all the necessary livestock activity data are readily available and of good quality. However, in most countries, there is plenty of information that, if systematized, provides a good starting point for compiling and maintaining an inventory using the Tier 2 approach. With an initial inventory based on the best available data, compiled using methods consistent with the IPCC good practice guidance and guidelines, systematic assessment can indicate ways to invest limited resources to achieve major and cost-effective improvements in filling information gaps and improving data quality. This approach to continuous improvement is in line with IPCC good practice guidance and guidelines and is recognized as a key principle of the Modalities, Procedures and Guidelines on transparency in the Paris Agreement Annex, paragraph 3).

Purpose and scope of this guidance

The aim of the Livestock Activity Data Guidance (L-ADG) is to provide practical methods for countries to estimate the activity data used to compile livestock GHG inventories using the IPCC Tier 2 approach. The purpose is to support countries to improve the accuracy of the livestock emission estimates in national GHG inventories, and thus enable countries to measure and report progress towards their NDCs. Intended readers include inventory experts with no livestock expertise and livestock experts who may be unfamiliar with the IPCC Guidelines on GHG inventory compilation. Because of the potential complexity of livestock activity data compilation and the demands on time and resources, it is common for compilation of Tier 2 livestock GHG inventories to be contracted out by the inventory compilation agency. However, it is important for the inventory compiler to understand all the principles in this guidance so that they can write up the contract description and know exactly what is required, and so that they can then assess the quality of the data provided by the contractor.

In the current UNFCCC framework for MRV, developing countries should use the IPCC 1996 Guidelines and 2000 Good Practice Guidance, and may optionally refer to the 2006 Guidelines. The L-ADG is based on the 2006 IPCC Guidelines for National GHG Inventories, which is the guidelines recommended for all countries under the Modalities, Procedures and Guidelines on transparency in the Paris Agreement (Annex, paragraph 20). The livestock emission sources covered as defined in the IPCC 2006 Guidelines (Vol. 1 Ch. 8), include:

- enteric fermentation (IPCC 2006 reporting category 3A1)
- methane and nitrous oxide manure management (IPCC 2006 reporting category 3A2)
- direct and indirect nitrous oxide emissions from urine and dung N deposit on pasture (IPCC 2006 reporting categories 3C4 and 3C5), and
- indirect nitrous oxide emissions from manure management (IPCC 2006 reporting category 3C6).

GHG emissions due to application of manure on cropland or other soils are not covered in the L-ADG, since estimates of these emission sources often use quite different activity data sources from those used to estimate livestock manure management emissions. However, many of the principles and methods for compiling this data are the same.

The L-ADG focuses on estimating activity data from the main ruminant types often found in developing countries: cattle, sheep and goats. For each emission source, the L-ADG provides guidance on how to compile the activity data required for the equations described in the 2006 IPCC Guidelines. The IPCC Guidelines also note that where well-documented and recognized country-specific models exist, it is good practice to use those models in place of the IPCC equations. This guidance focuses on activity data compilation, and does not provide guidance on estimation of conversion factors or other default variables in the IPCC equations, which are already described in the IPCC Guidelines (Vol. 4 Ch. 10).

In particular, the L-ADG presents guidance on how to:

- Identify and assess the availability and quality of existing activity data;
- Structure a Tier 2 inventory to make use of available data;
- Compile activity data when data exists but is incomplete or of insufficient quality;
- Estimate activity data when data is missing;
- Assess the quality of data and identify priorities for continuous improvement.

The L-ADG complements the IPCC guidance by:

- Giving an overview of the IPCC guidelines and related UNFCCC decisions;
- Providing practical guidance on how to implement the IPCC guidelines, including tools to support decision making and worked examples of how the practical guidance can be implemented;
- Explaining methodological issues affecting decisions about how to compile activity data; and
- providing links to additional resources for readers to consult.

How this guidance was developed

The development of the L-ADG began with a review of current practices in measurement, reporting and verification of livestock emissions by developing countries. That document identified an opportunity for more developing countries to adopt Tier 2 approaches for livestock GHG inventories, and found that lack of activity data is a common perceived constraint. This was followed by compiling a set of case studies of how Tier 2 approaches have been implemented by both developed and developing countries. These case studies are available as a downloadable document or as a set of individual case studies that can be found on www.agmrv.org. Further consultation with stakeholders identified the need for practical guidance on how to compile activity data for Tier 2 livestock GHG inventories. The **Authors** drafted the guidance with advice from an **Advisory Group**. The L-ADG was compiled around the same time as Kenya developed its first Tier 2 inventory for dairy cattle with support from the GRA, and several examples in the L-ADG are drawn from that experience.

How to use this guidance

The Modalities, Procedures and Guidelines on transparency in the Paris Agreement (Annex, paragraph 20) clarify that Parties to the Paris Agreement shall use the 2006 IPCC Guidelines for National GHG Inventories. This L-ADG document is designed to complement the IPCC Guidelines and provide practical guidance on how to implement the IPCC Guidelines when compiling livestock GHG inventories using the IPCC Tier 2 approach. To do this, the L-ADG presents a framework for activity data compilation (**Figure 1**). For each step in the framework, this document gives practical guidance, references to the relevant IPCC Guidelines and UNFCCC decisions, tools, worked examples and links to additional resources.

Framework for activity data compilation

The framework for activity data compilation is based on 8 steps (**Figure 1**).

Step 1: Define activity data needs. This step involves deciding **what livestock sub-categories to represent** in the inventory, clarifying **what parameters need to be estimated** using activity data, and deciding **how to represent change in the time series** for emission estimates.

Step 2: Collect activity data. This step involves **identifying stakeholders** who may be able to provide data, **establishing institutional arrangements** for obtaining data, and **gathering all the available relevant data**.

Step 3: Assess data availability. This step involves systematically assessing **what data is available** to characterise livestock sub-populations in a consistent way over time. It may result in identifying **information gaps** when no data is available. The dashed line in **Figure 1** shows that this may require re-defining the livestock sub-categories in the inventory.

Step 4: Assess data quality. Even if data is identified in Step 3, it may not all be of adequate quality. This step involves **assessing the quality of available data**. It may result in identifying **data quality gaps**, i.e. when there is available data but it is of **inadequate quality**.

Step 5: Fill data gaps. This step involves **filling data gaps** due to lack of information or lack of adequate quality data either by **using existing data** or by **collecting new data**. For collecting new data, this guidance focuses on methods that can provide data to meet the immediate needs of inventory compilation, including expert opinion and IPCC default values. Longer-term improvements in data collection are addressed in Step 8.

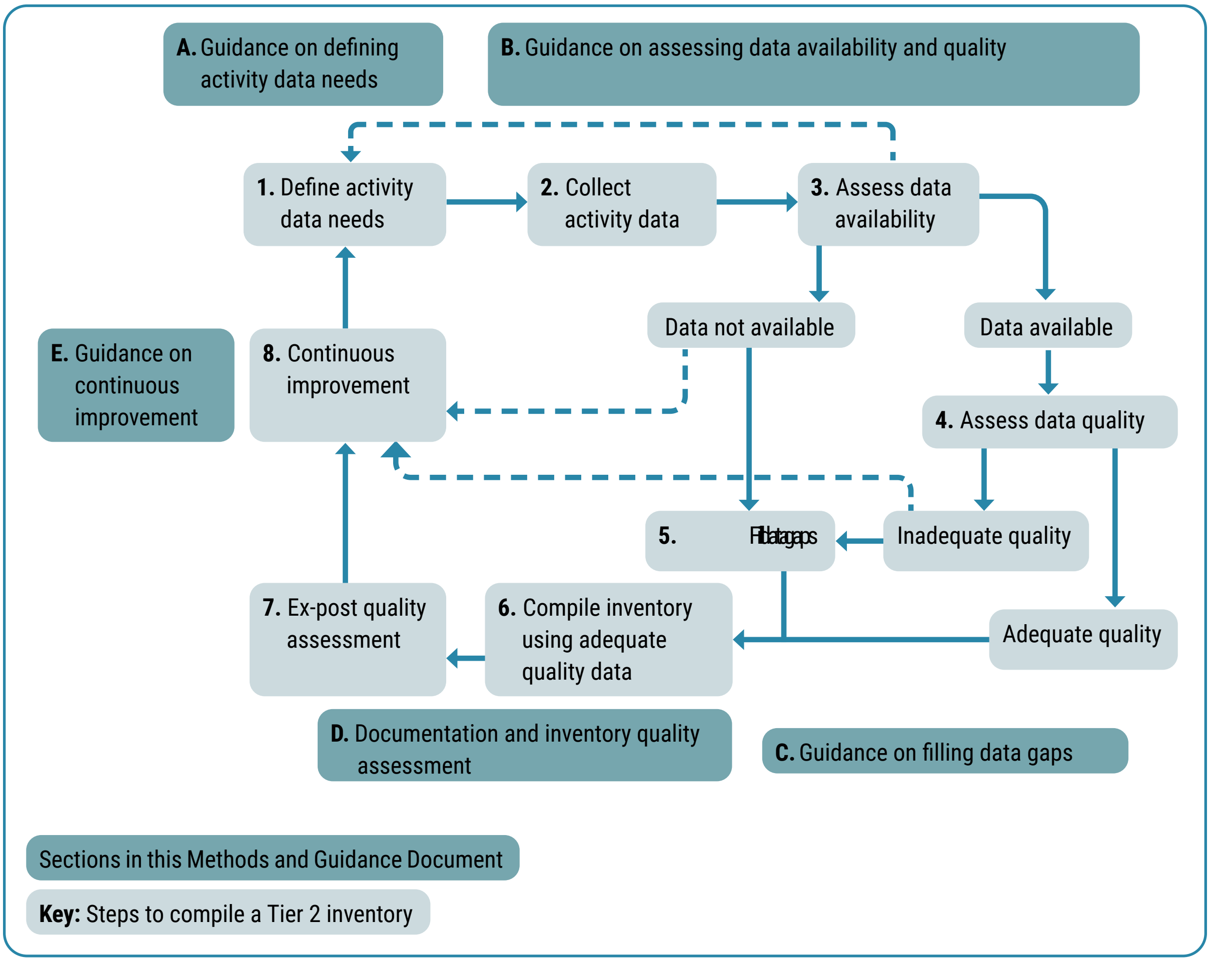
Step 6: Compile the inventory using adequate quality data. Data that has been collected and assessed as of adequate quality are used to compile an initial inventory, which should be **transparently documented**, and **quality control** activities are implemented.

Step 7: Inventory quality assessment. This step uses **data quality assessment, quality assurance**, and **uncertainty analysis** to identify priorities for inventory improvement.

Step 8: Continual improvement. This step involves drafting and implementing an inventory improvement plan. The plan may also include efforts to improve the availability or quality of national livestock statistics to meet the needs of future inventories.

When compiling a Tier 2 inventory for the first time, users can follow Steps 1 to 8 in sequence. If work on a Tier 2 inventory has already begun, users can enter the process at any step. Because the process is a cycle, it can also be used to guide continual improvement.

Figure 1: Activity data compilation framework



The 8 steps in the Activity Data Compilation Framework are covered in five sections of the L-ADG document. These five sections cover the following questions:

Section A: How to define what data is needed?

Section B: How to collect the data needed, and how to assess data availability and data quality?

Section C: How to fill data gaps?

Section D: How to document the inventory and assess inventory quality?

Section E: How to plan for continuous improvement?

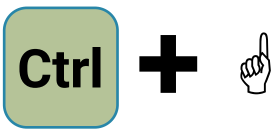
Each section contains the following elements:

1. **Practical guidance** on compilation of activity data, including general step-by-step guidance and guidance on the specific parameters described by the IPCC 2006 Guidelines;
2. Links to and overviews of related **IPCC good practice guidance and guidelines and UNFCCC decisions**;
3. **Useful tools** for implementing the practical guidance;
4. **Methodological guidanc**e that explains issues affecting decisions about how to compile activity data;
5. **Worked exampl**es of how to implement the practical guidance; and
6. Links to **additional resources**.

You can view this overall structure in the Main Navigation Page. The document has been structured to allow readers to move between different parts of the document:

Readers can use the **Main Navigation Page** to select and go to sections and elements in each section.

In the text, words that are highlighted in blue – e.g. **Main Navigation Page** – indicate a link to a resource in another element. Use Ctrl+Click to follow the link, and use Alt+Left arrow to return to your previous position in the document.



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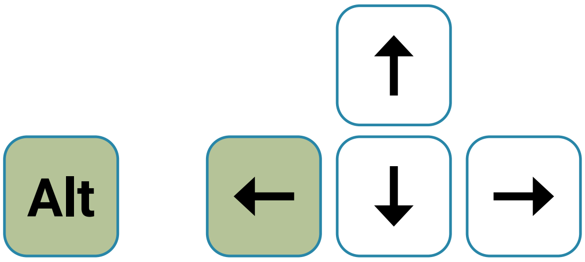

To return, use Alt+Left arrow:

- Links to external resources are indicated like this: IPCC (2006) Vol. 4 Ch. 10. Use Ctrl+Click to follow the link using your web browser.
- Readers can also navigate the contents using the Navigation Pane to the left. To access the Navigation Pane, click "◀" on the left margin bar.

Main Navigation Page

Access each sub-section with Ctrl+Click on the text in each cell.

About the Livestock Activity Data Guidance

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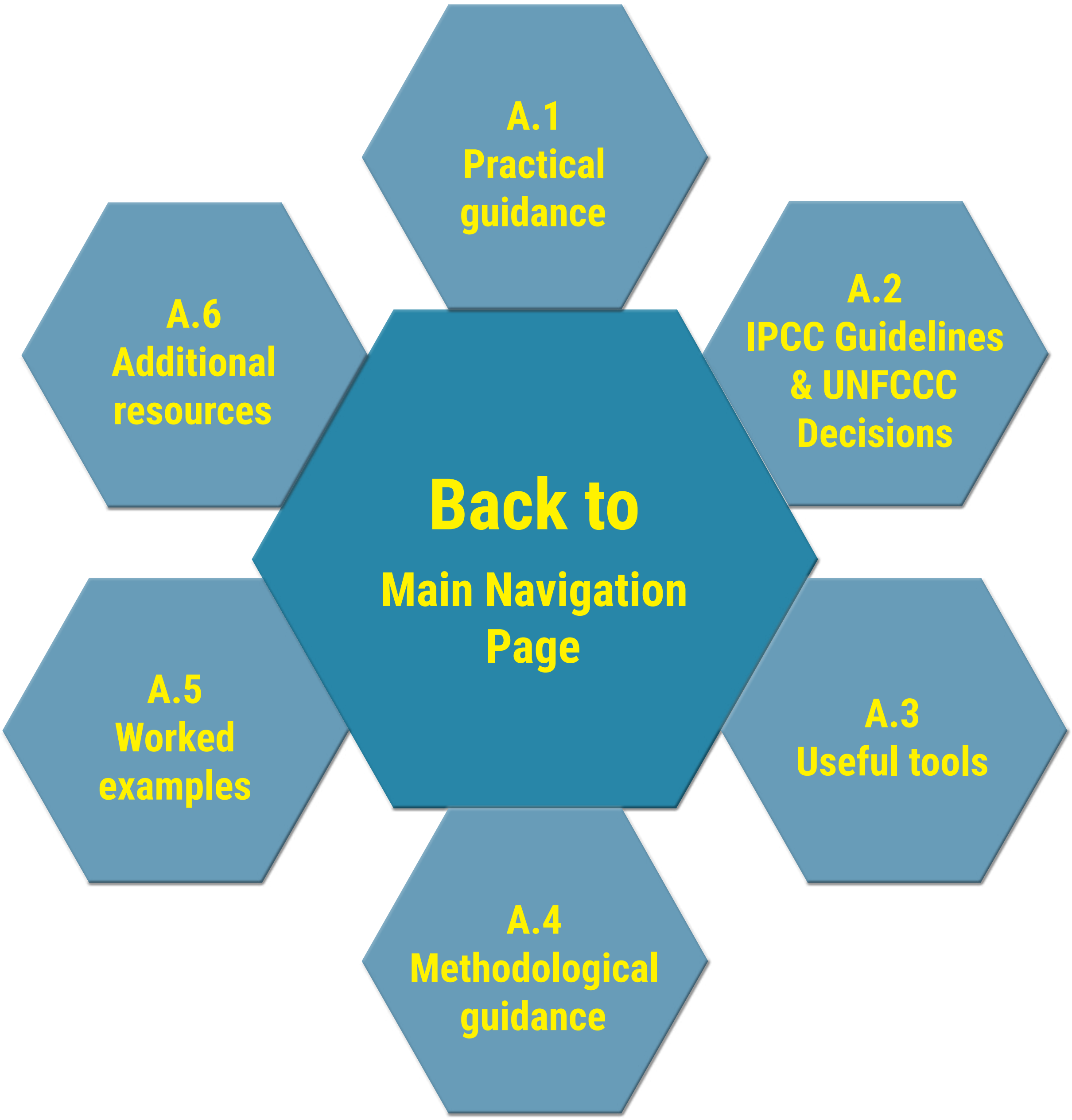
A. Define activity data needs



A.1 Practical guidance

A Tier 1 approach uses national data on each livestock type (e.g. dairy or other cattle, sheep, goats) and the IPCC default emission factors to estimate GHG emissions in each year. The default emission factors given by the IPCC are general estimates for each continental region and will not accurately reflect actual conditions in any one country. In the Tier 1 approach, the emission factors used do not change over time, so they cannot reflect the effects of changes in herd structure, management or productivity, or the effect of mitigation policies and measures. IPCC Tier 1 and Tier 2 approaches are compared in **Methodological Focus A.1 Tier 1 and Tier 2 approaches compared**. **Methodological Focus A.2: When to use a Tier 2 approach** gives guidance on when to use a Tier 2 approach, and **Methodological Focus A.3: Potential benefits and limitations of a Tier 2 approach** explains the potential benefits and limitations of using the Tier 2 approach in a national GHG inventory.

When beginning to develop a Tier 2 livestock inventory there are three key aspects to consider. These three aspects will determine what specific activity data is required:

1. **Livestock characterization and inventory structure:** The Tier 2 approach is applied to sub-categories of each livestock type, such as male or female adult cattle, growing male and female cattle, and calves. Animal sub-categories may also be categorized in other ways, such as by region or by production system. How these sub-categories are defined determines the inventory structure. Practical guidance on **Livestock characterization and inventory structure** is given in the following section.

2. **The IPCC Tier 2 equations and their parameters:** The IPCC Guidelines (Vol. 4 Ch. 10) presents equations that can be used to estimate emissions from enteric fermentation and manure management. Equations to estimate nitrous oxide emissions from deposit of dung and urine on pasture are given in Vol. 4 Ch. 11. Each set of equations requires that values for input parameters are estimated using activity data. The parameters that need to be estimated using activity data are described in the section on **The IPCC Tier 2 equations and their parameters**.

3. **Representing change over time:** When a Tier 2 approach is first used in a GHG inventory, the time series for each emission source should be estimated for every year since the inventory base year. For most developing countries this is 1990 or 1994.[1] Deciding whether and how to represent change in the livestock sector will determine the activity data needs and may influence inventory structure. Practical guidance is given on **How to represent change over time**.

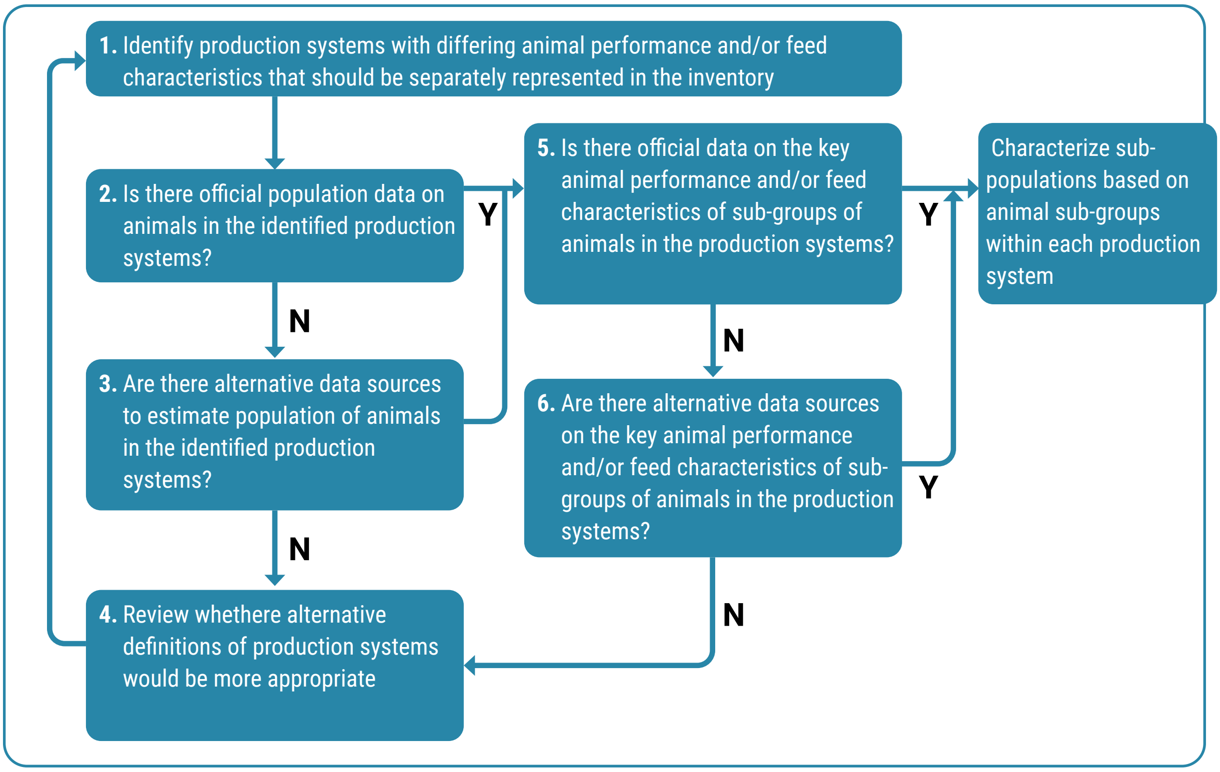
[1] See UNFCCC Decision 17/CP.8.

Livestock characterization and inventory structure

Livestock characterization means to identify sub-categories of each livestock type that are relatively homogenous and that reflect country-specific variation in herd structure and animal performance. Livestock characterization plays a key role in Tier 2 inventory compilation, because how livestock sub-categories are defined determines the specific data required to compile the inventory. Livestock characterization therefore determines the structure of the inventory, the complexity of activity data collection in future years, and the ability of the inventory to track the effects of mitigation policies and measures over time (see **Methodological Focus A.5: The importance of livestock characterization for inventory structure and function**).

The IPCC Guidelines (Vol. 4 Ch. 10) provides guidance on livestock characterization. A summary is given in **IPCC guidelines on livestock characterization**. The IPCC Guidelines suggest to characterize livestock "to the level of detail required". But what level of detail and how many sub-categories are required? What criteria should be used to define livestock sub-categories? Country circumstances vary, so there will be no single answer to these questions. This section suggests a set of guiding questions as part of a step by step process for deciding how to characterize livestock and structure the inventory. Livestock sub-categories should be decided through an iterative process based on the assessment of data availability and quality, as shown in **Figure 2**.

Figure 2: Decision tree for livestock characterization



In brief:

- The starting point is to propose livestock sub-categories that will enable the Tier 2 inventory to fulfil its intended functions of improving inventory accuracy and tracking change over time.

- Next, assess whether data is available to quantify the population of each proposed sub-group.
- Then, assess whether data is available to characterize the management and performance of each proposed sub-group.

If data is not available to support quantification of populations or characterization of animal sub-groups, then the proposed categorization of livestock sub-categories should be revised and data availability re-assessed. However, if particular sub-categories that cannot be quantified or characterized are required to ensure that the inventory meets policy or other needs, these sub-categories may be retained, populated with IPCC default values or expert opinion for animal characterization, and targeted for future improvements. The step-by-step approach is described below.

1 Identify livestock sub-categories that should be represented in the inventory

Identify potential livestock sub-categories along two dimensions: production systems and animal sub-types.

Production system categories: Emissions per animal may vary significantly depending on feed, management practices or animal performance (see **Methodological Focus A.6: Which types of activity data are likely to have the biggest impact on emission factors?**). These differences may be associated with differences in feeding system, type of farm enterprise, agro-ecological or climate zone, geographical region or other factors. The objective is to identify production systems in the country with animals of the same livestock type that have significant differences in feeding, management practices or animal performance. Guiding questions to help identify production system categories include:

- What differences in production systems are associated with significant differences herd structure, animal performance, management or feed?
- Which production systems are expected to undergo significant change in scale (e.g. animal numbers), animal performance (e.g. productivity) or feeding management (e.g. stall-feeding)? These changes may be due to longer-term trends in the livestock sector, or due to livestock development or GHG mitigation policies. Where significant future change is expected, these production systems should be explicitly represented in the inventory so that the inventory can track these changes.

Animal sub-types: Identify the sub-groups of animals within each production system that should be represented in the inventory. Within a given production system, sub-groups should be identified by age, sex and, if appropriate, other factors associated with significant differences in animal performance, feed or management. Proposing livestock categories should be done in consultation with sector experts and industry organisations.

It is also possible to define only one production system for each livestock type. More production systems and more animal sub-categories will not necessarily make a better inventory (see **Methodological Focus A.7: Will more sub-categories make a more accurate inventory?** and it is also possible to combine sub-categories without losing accuracy (see **Methodological Focus A.8: Disaggregating and combining categories**). The pros and cons of structuring the inventory around geographical or climate regions are discussed in **Methodological Focus A.9: Representing geographic or climate regions in livestock inventories**.

2 Is there official population data for livestock sub-categories in each production system?

If 'Yes', then, proceed to Step 5. For further guidance on assessing data availability for livestock populations, see Section **B. Assess data availability and quality**. If 'No', then proceed to Step 3.

3 Are there alternative data sources to estimate livestock sub-category populations in each production system?

Alternative data sources may include data from industry bodies or other non-official sources (see the list of potential data sources on livestock sub-populations in **Tool B.2**) or sub-populations may be estimated by combining different data sources (see **C.1.1 Filling data gaps using available data**). If alternative data is identified, then proceed to Step 5. If 'No', then proceed to Step 4.

4 Review whether alternative definitions of production systems would be more appropriate

Review alternative categories of production systems and return to Step 1, or determine whether the unquantifiable categories need to be retained for other reasons (e.g. to track policies or other future changes).

After sub-category population data sources have been identified:

5 Is there official data on key animal performance and/or feed characteristics of animal sub-categories in each production system

For guidance on identifying which animal performance or feed characteristics may be key influencing factors, see **Methodological Focus A.6: Which types of activity data are likely to have the biggest impact on emission factors?** If 'Yes', then data is available to characterise livestock sub-populations on the basis of the categories identified. If 'No', then go to Step 6.

6 Are there alternative data sources on key animal performance and/or feed characteristics of animal sub-categories in each production system?

For guidance on identifying alternative data sources for animal performance and feed characteristics, see Section **B. Assess data availability and quality**. If 'Yes', then data is available to characterise livestock sub-populations on the basis of the categories identified. If 'No', then go to Step 4, and review alternative ways to define livestock sub-categories and return to Step 1, or determine whether the sub-categories that cannot currently be characterized need to be retained for other reasons (e.g. to track policies or other future changes).

Where inventory compilers have in-depth prior knowledge of the sector and available data, proposing categories for which data exists may be straightforward. In other cases, it will be necessary to engage with sector experts and stakeholders, collect available data, and then assess whether the proposed categories can be represented using the available data. Guidance on collecting and assessing available data is the main topic of Section **B. Assess data availability and quality**.

In some situations, production systems or sub-categories may be proposed for which populations or animal characteristics cannot be quantified, However, inventory compilers may wish for other reasons to retain this category. For example, tracking change in a particular production system or sub-category may be important to enable the inventory to track the effects of national policies. Inventory compilers may decide to retain these categories, use IPCC default data, expert judgement or other data sources for the initial inventory and focus future improvement efforts on these categories.

The IPCC Tier 2 equations and their parameters

The IPCC Guidelines (Vol. 4 Ch. 10) recommends a specific set of equations for estimating enteric fermentation emissions that is largely based on ruminant net energy equations described in publications by the National Research Council of the United States. In brief, emission factors for each animal category are based on estimated daily gross energy intake (GE) or feed intake (expressed as dry matter intake, DMI) and a methane conversion rate (Y_m, % of gross energy in feed converted to methane). Daily emissions per head are then converted to annual emissions per head:

$$EF = \left[\frac{GE \times \frac{Y_m}{100} \times 365}{55.65} \right]$$ (IPCC 2006 Equation 10.21)

where:

EF_i =emission factor (kg CH_4 head^{-1} year^{-1})
GE = gross energy intake (MJ head^{-1} day^{-1})
Y_m = methane conversion rate (% of gross energy in feed converted to methane)
55.65 = energy content of methane (MJ/kg CH_4)

Since direct measurements of feed intake are rarely available, the IPCC equations estimate gross energy intake from animal performance data reflecting the net energy required for maintenance, activity, growth, lactation, work and pregnancy. Animal performance is characterised using activity data.

Gross energy is also a key input to the IPCC Tier 2 equations for manure management emissions. For manure management, annual emissions per head are estimated using additional activity data on the fraction of manure managed in different manure management systems, mean annual temperature, crude protein content in the diet, and milk protein content.

The activity data required to estimate gross energy intake for ruminants and manure management emissions using the IPCC equations is shown in **Table 1**. Technical definitions for each parameter are given in **Tool A.1**. Further guidance on the indicators that can be used to estimate each parameter and potential data sources are given in Section **B.1.2 Guidance for specific parameters**. Correct implementation of the IPCC equations and the correct use of units is essential to avoid errors in emission calculations. **Tool A.2: Spreadsheet templates for IPCC Tier 2 livestock emission sources** provides the IPCC Tier 2 equations programmed in a spreadsheet that can be used as the template for initial Tier 2 inventory..

How to represent change over time

IPCC Guidelines state that when a Tier 2 approach is first used in a GHG inventory, the time series for each emission source should be estimated for every year since the inventory base year (or, in the Modalities, Procedures and Guidelines on transparency in the Paris Agreement, at a minimum since the reference year in the country's NDC).[2] See the summary of time series consistency in **A.2 IPCC Guidelines & UNFCCC Decisions**. For most countries the inventory base year is 1990 or 1994. In the decades since the 1990s, some livestock sub-sectors have changed dramatically. Change in types of livestock farm, breeds and feeding practices, or changes in the regional distribution of animals are likely to have affected emissions per animal and total emissions. However, management of some animal types has not changed at all (see **Methodological Focus A.4: Rates of productivity change in the livestock sector**).

If a livestock sub-sector has changed, these changes should be reflected in the activity data used. In this case, when collecting activity data (see Section **B. Assess data availability and quality**), attention should be paid to identifying data sources from different historical years. If there is only sufficient activity data to estimate parameters for some years, time series gap filling methods can be used, which are described in **C.1.1 Filling data gaps using available data**. If there is only data for certain periods in the time series, activity data can be characterized for discrete periods, as shown in **Worked example A.1: Characterizing activity data for historical periods**.

If a livestock sub-sector has not changed in recent decades, it may be sufficient to collect

[2] The entire time series should also be recalculated if any changes have been made to the methodology used or if there are changes to parameters that are applied to all years in the time series.

Table 1: Activity data required in the IPCC Tier 2 enteric fermentation and manure management equations

Parameter	Description / definition	Cattle / buffalo	Sheep / goats
Population	Population of animals of different types (head)	✓	✓
Body weight	Live weight per animal type (kg)	✓	✓
Mature weight	Weight of mature animals (kg). Defined as shrunken body weight of mature animals in moderate body condition.	✓	
Weight gain	Average daily weight gain (kg per day). Applied only to growing animals.	✓	
Body weight at weaning	Body weight at weaning (kg)		✓
Body weight at 1 year old	Body weight at 1 year or slaughter if before 1 year (kg)		✓
Lamb weight gain between birth and weaning	Lamb weight gain between birth and weaning (kg)		✓
Milk yield	Annual average daily milk yield (kg per day)	✓	✓
Fat content of milk	Average fat content of milk (%)	✓	✓
Fraction of adult females pregnant	Used in applying coefficient for pregnancy and coefficient for maintenance	✓	✓
Number of births	% of adult females giving birth to single, twins or triplets		✓
Feeding situation	Stall-fed, grazing confined pasture or extensive grazing. Used in applying coefficient for activity	✓	✓
Hours worked	Annual average number of hours of work per day	✓	
Wool production	Wool production per head per year (kg)		✓
Feed digestibility	Digestible energy as a % of gross energy	✓	✓
Fraction of manure managed in different systems	Fraction of manure from each type of livestock managed in different manure management system in different climate regions	✓	✓
Mean annual temperature	Mean annual temperature where livestock are located (°C)	✓	✓
Crude protein content of diet	Average crude protein content of the diet (%)	✓	
Protein content of milk	Protein content of milk (%)	✓	

all available activity data for each inventory sub-category. Activity data that may have been collected in different years would then be used to estimate a single emission factor for each animal sub-category, with emissions from each source changing as population data changes. This is similar to a country-specific Tier 1 approach.

In some cases, the inventory compiler may clearly understand whether a sub-sector has changed or not. If it is not immediately clear, when stakeholders are engaged for activity data collection (see **B.1.1 General guidance**), the inventory compiler can consult with stakeholders to better understand the changes that have taken place. This may help in prioritizing time and resources for activity data compilation from more recent or historical periods. After collecting the available activity data, it should also be assessed whether there are reliable indications of change that should be reflected in the inventory time series for each parameter.

In either case, the time series should be estimated using consistent methods and to the extent possible consistent data sources for each parameter. See the summary of IPCC Guidelines on time series consistency in **A.2 IPCC Guidelines & UNFCCC Decisions**.

A.2 IPCC Guidelines and UNFCCC Decisions

This section summarizes:

IPCC guidelines and UNFCCC Decisions on when to use a Tier 2 approach

IPCC guidelines on livestock characterization and

IPCC Guidelines on time series consistency.

IPCC guidelines and UNFCCC Decisions on when to use a Tier 2 approach

A 'key category' in an inventory is an emission source that has a significant influence on the total level, trend or uncertainty of the total GHG inventory. The 2006 IPCC Guidelines (Vol. 1 Ch. 4) states that it is good practice to identify key categories in the national inventory, and to use the results of key category analysis as the basis for methodological choice. For livestock emissions, IPCC (2006) Vol. 4 Ch. 10 (Figures 10.2 and 10.3) suggests that a Tier 2 method should be used for enteric fermentation and/or manure management emissions if these sources are key categories in the GHG inventory. If a livestock species (e.g. cattle or sheep) accounts for 25% or more of enteric fermentation or manure management emissions, a Tier 2 approach should be applied to that species. Specific instructions on how to apply key category analysis to the national inventory are given in the 2006 IPCC Guidelines (Vol. 1 Ch. 4).

The Modalities, Procedures and Guidelines on transparency in the Paris Agreement (Annex, paragraph 21) also states that IPCC guidelines on choice of method should be followed. It further notes that if a Party lacks the resources to adopt a higher tier method, the national inventory report shall document why the IPCC decision trees for methodological choice were not followed, and shall prioritize these key categories for future improvement.

Although it is not mentioned in IPCC or UNFCCC documents, **Methodological Focus A.2: When to use a Tier 2 approach** also suggests that a Tier 2 approach can be adopted when the livestock sector is included in a country's NDC, because a Tier 2 approach is better able to track change in emissions due to mitigation policies.

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IPCC guidelines on livestock characterization

The aim of livestock characterization is to produce “relatively homogenous sub-groupings of animals” that can reasonably be estimated by the same emission factor and that reflect country-specific features of the livestock sector (2006 IPCC Guidelines, Vol. 4 Ch. 10).

IPCC states that it is good practice to categorize livestock on the basis of age, sex and production system. Further suggestions are made on possible sub-categories for different livestock types, as shown in Table 2. IPCC guidance refers to animal and feed characteristics as possible criteria for categorizing sub-groups of each livestock type. Animal or feed characteristics may have regional differences.

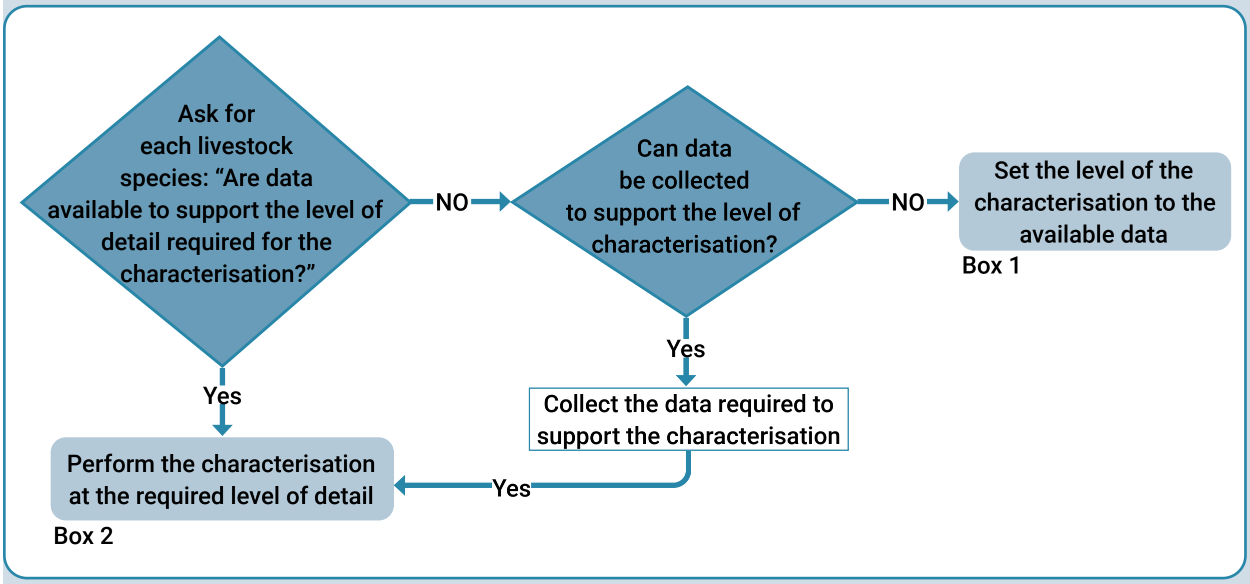
Table 2: Recommended representative livestock categories in the 2006 IPCC Guidelines

Main categories	Subcategories
Mature dairy cow or mature dairy buffalo	• High-producing cows that have calved at least once and are used principally for milk production • Low-producing cows that have calved at least once and are used principally for milk production
Other mature cattle or mature non-dairy buffalo	Females: • Cows used to produce offspring for meat • Cows used for more than one production purpose: milk, meat, draft Males: • Bulls used principally for breeding purposes • Bullocks used principally for draft power
Growing cattle or growing buffalo	• Calves pre-weaning • Replacement dairy heifers • Growing / fattening cattle or buffalo post-weaning • Feedlot-fed cattle on diets containing >90% concentrates
Mature ewes	• Breeding ewes for production of offspring and wool production • Milking ewes where commercial milk production is the primary purpose
Other mature sheep (>1 year)	• No further sub-categorisation recommended
Growing lambs	• Intact males • Castrates • Females

Source: IPCC (2006) Table 10.1

The IPCC Guidelines provides a decision tree to guide categorization of livestock. The IPCC Guidelines provides a decision tree to guide categorization of livestock (IPCC 2006, Figure 10.1, partially reproduced in Figure 3). The decision tree highlights the importance of having available data to support characterization of the livestock sub-categories identified. However, if country-specific data is missing for livestock sub-categories, the Tier 2 approach can still be applied using IPCC default values or values estimated on the basis of expert opinion.

Figure 3: Part of the IPCC decision tree on livestock characterization



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IPCC Guidelines on time series consistency

IPCC Guidelines on time series consistency (Vol. 1 Ch. 5) points out that the time series for each parameter may influence the historical trend in emissions and the ability of the GHG inventory to track the effects of mitigation policies and measures. The trend in time series should be neither over- nor under-estimated as far as can be judged. Challenges to time series consistency include changes in data availability, changes in inventory capacity and techniques for inventory compilation.

Time series consistency can be ensured if the same method and same data sources are used in all years. Therefore,

- When a Tier 2 approach is adopted in the inventory, it should be applied to all years back to the inventory base year, which is 1990 or 1994 for most countries.[3]
- The same level of disaggregation (i.e. same inventory sub-categories) should be used throughout the time series. If sub-categories are changed (e.g. as more information becomes available), the inventory time series should be recalculated using the new sub-categories.

Data gaps in a historical time series can be filled using time series gap filling methods described in the 2006 IPCC Guidelines (Vol. 1 Ch. 5). The Annex to the Modalities, Procedures and Guidelines on transparency of the Paris Agreement (paragraphs 26-28) also stress the importance of using the same methods and a consistent approach to

[3] UNFCCC Decision 17/CP.8.

the underlying activity data in each year. It also refers to the IPCC time series gap filling methods, which are described in **C.1.1 Filling data gaps using available data**.

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A.3 Useful tools

This section contains two tools:

Tool A.1: Technical definitions of IPCC activity data parameters

Tool A.2: Spreadsheet templates for IPCC Tier 2 livestock emission sources

Tool A.1: Technical definitions of IPCC activity data parameters

Parameter	Abbrev.	Units	Description / definition
Population	N	head	Annual average population of each livestock sub-category. For further guidance on calculating annual average population, see **Methodological Focus B.3: When do I need to estimate the number of days alive for a livestock sub-category?**.
Body weight	BW	kg	Average live weight of each animal sub-category (kg).
Mature weight	MW	kg	Shrunk body weight of mature animals (kg). For further guidance see **Live weight, mature weight and weight gain**.
Weight gain	WG	kg day^{-1}	Average daily weight gain (kg per day). May be applied only to growing animals.
Body weight at weaning	BW_i	kg	Body weight at weaning (kg). Applied to lambs only.
Body weight at 1 year old	BW_f	kg	Body weight at 1 year or slaughter if before 1 year (kg). Applied to lambs only.
Lamb weight gain between birth and weaning	WG_{lamb}	kg	Difference between live weight at birth and at weaning (kg). Applied to lambs only.
Milk yield	Milk	kg day^{-1}	Annual average daily milk yield (kg per day). This is the average per calendar day, not per lactation day.
Fat content of milk	Fat	%	Average fat content of milk (%). Applied to adult females only.
Fraction of adult females giving birth	-	fraction	Fraction of adult females giving birth in a calendar year.
Fraction of females giving birth to multiple offspring	-	fraction	Fraction breeding females giving birth to single lambs, twins or triplets. Applied to adult female sheep/goats only.
Feeding situation	-	-	Categorization of animals as stall-fed, grazing confined pasture or grazing extensive rangeland. For further guidance see **Feeding situation and livestock activity**.
Hours worked	Hours	hours day^{-1}	Annual average number of hours of work per day. Applied to cattle only.
Wool production	$Production_{wool}$	kg $year^{-1}$	Wool production (dry matter before scouring) per head per year (kg).

Parameter	Abbrev.	Units	Description / definition
Feed digestibility	DE	%	Digestible energy as a percent of gross energy (%). For further guidance see **Feed composition and digestibility**.
Fraction of manure managed in different systems	$MS_{(T,S,k)}$	fraction	fraction of manure from each type of livestock managed in different manure management system in different climate regions
Mean annual temperature	MAT	°C	Mean annual temperature (°C) where livestock are located
Crude protein content of the diet	CP%	%	Average crude protein content (%) of the diet.
Protein content of milk	Milk PR%	%	Average protein content of milk (%)

*Further guidance on each parameter is given in **B.1.2 Guidance for specific parameters**

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Tool A.2: Spreadsheet templates for IPCC Tier 2 livestock emission sources

National GHG inventories are often compiled using specialist software, such as the IPCC Inventory Software or ALU Software. The ALU Software has functions to implement the Tier 2 equations for livestock emission sources, and activity data can be directly input into the ALU Software. The IPCC Inventory Software currently (Version 2.54) does not have the function to implement the IPCC Tier 2 equations for livestock emissions. Tier 2 livestock emissions must be calculated in another software and the population data and Tier 2 emission factors are then entered into the IPCC Inventory Software.

Tier 2 livestock inventories are therefore often compiled using custom-made spreadsheets. One benefit of using custom-made spreadsheets is that inventory compilers have a clear view of exactly how the calculations are made. However, there are many equations to programme into the spreadsheet, and there is a risk of errors in either the programmed equations or the units. For example, when milk fat content (%) should be entered as a %, it is correct to enter "4", but not correct to enter "4%".

To support inventory compilation using custom-made spreadsheets, **Tool A.2: Spreadsheet templates for IPCC Tier 2 livestock emission sources** is a Microsoft Excel spreadsheet containing draft templates for calculation of livestock emissions (see **Table 3** for list of emission sources included). The templates in that tool should be adjusted to reflect the inventory structure and can be further edited to reflect any country-specific adjustments to how the IPCC equations are implemented. The ALU Software, which can also calculate

Tier 2 emissions, can also be used as a cross-check for estimates made using custom spreadsheets.

Table 3: Emission sources included in the spreadsheet template Tool A.2

Category code and name*	Gases	Source for equations implemented
3A1a Enteric fermentation, cattle	CH_4	IPCC (2006) Vol. 4 Ch. 10
3A1c Enteric fermentation, sheep	CH_4	IPCC (2006) Vol. 4 Ch. 10
3A2a Manure management, cattle	CH_4, N_2O	IPCC (2006) Vol. 4 Ch. 10
3A2c Manure management, sheep	CH_4, N_2O	IPCC (2006) Vol. 4 Ch. 10
3C4 Direct N_2O emissions from managed soils (urine and dung N deposited on pasture only)**	N_2O	IPCC (2006) Vol. 4 Ch. 11
3C5 Indirect N_2O emissions from managed soils (urine and dung N deposited on pasture only)**	N_2O	IPCC (2006) Vol. 4 Ch. 11
3C6 Indirect N_2O emissions from manure management	N_2O	IPCC (2006) Vol. 4 Ch. 10

** Following the categorization in IPCC (2006) Vol. 1 Ch. 8.*
***The templates do not include equations for estimating emissions from application of animal manure to managed soils because the activity data are typically compiled as part of cropland management inventory activities.*

Tool A.2: Spreadsheet templates for IPCC Tier 2 livestock emission sources can be downloaded from this external link: https://www.agmrv.org/knowledge-portal/resources/spreadsheet-templates-for-ipcc-tier-2-livestock-emission-sources/

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A.4 Methodological guidance

This section explains methodological issues that affect how inventory compilation decisions may be made. The focus topics are:

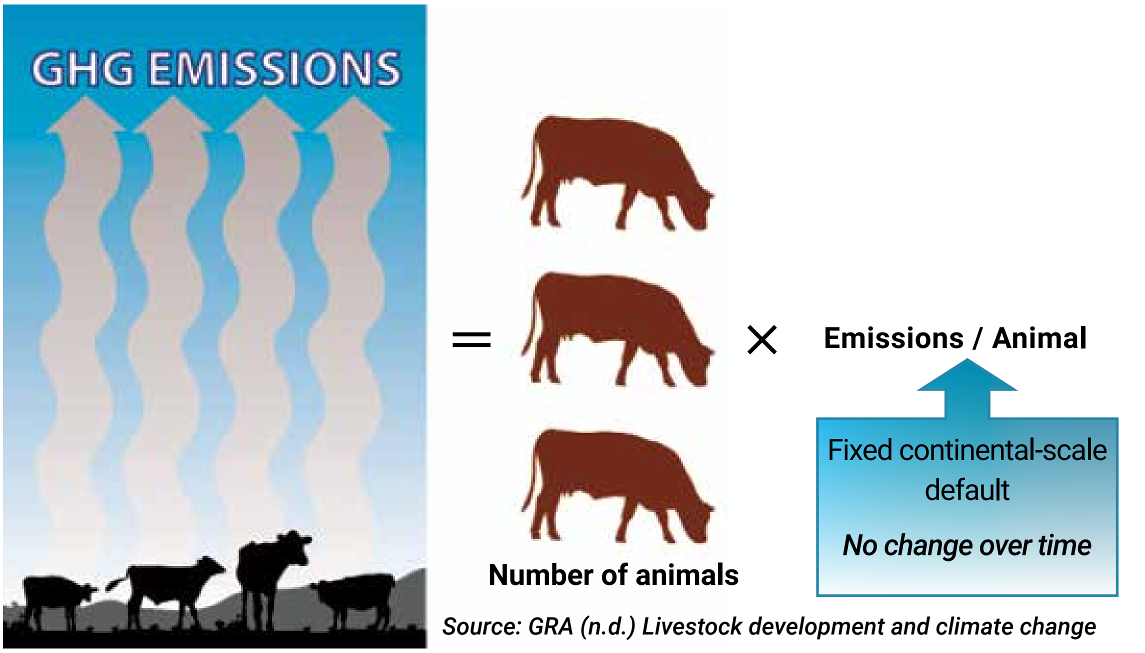
Methodological Focus A.1 Tier 1 and Tier 2 approaches compared

Tier 1 methodologies use fixed values for GHG emissions per head of livestock, so changes in total emissions reflect only changes in livestock population (Figure 4). This approach assumes that animals of different ages and breeding status have the same emissions and that emissions per head do not vary over time. The IPCC Guidelines provide Tier 1 default values for emissions per animal per year, which are applicable to broad continental regions, and do not reflect specific circumstances within countries. With a Tier 1 approach, reductions in livestock emissions can only be achieved if total animal numbers decrease. The value of a Tier 1 approach to policy makers is therefore limited.[4]

A Tier 2 approach requires more detailed information on different types of livestock in a country, and activity data on management practices and animal performance. These data are used to estimate feed intake (either as dry matter or as gross energy) required by the animals to maintain the specified level of performance. Intake is then converted to methane emissions by multiplying energy intake by a methane conversion factor (methane emissions per unit of energy intake) (Figure 5). Therefore, a Tier 2 approach is better able to reflect management practices, diets and animal productivity in different production systems or regions of a country. Emissions per animal estimated using a Tier 2 approach can also change over time if data on management practices or productivity are updated. A Tier 2 approach is therefore essential for capturing the effects of livestock development and climate change mitigation policies on emissions from the sector.

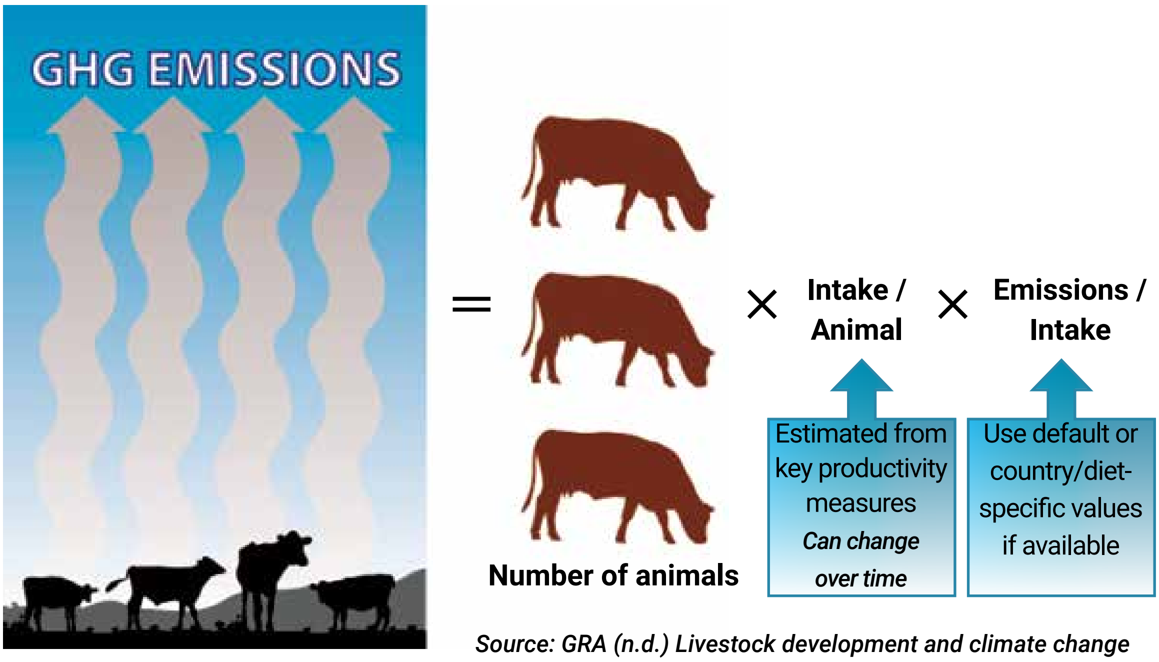
[4] The 2019 Refinement to the 2006 IPCC Guidelines introduces 'Tier 1a' which uses different emission factors for high and low productivity animals. Emissions can change if the proportion of the national herd in high or low production systems changes, but otherwise the Tier 1a approach is similar to the Tier 1 approach.

Figure 4: Tier 1 approach to estimating livestock emissions



Source: GRA (n.d.) Livestock development and climate change

Figure 5: Tier 2 approach to estimating livestock emissions



Source: GRA (n.d.) Livestock development and climate change

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Methodological Focus A.2: When to use a Tier 2 approach

IPCC (2006) VOL. 4 Ch. 10 (Figures 10.2 and 10.3) suggests that a Tier 2 method should be used for enteric fermentation and/or manure management methane emissions if they are key categories in the GHG inventory. A key category is an emission source that is a priority in the inventory because "its estimate has a significant effect on a country's total inventory of greenhouse gases in terms of the absolute level, the trend, or the uncertainty in emissions and removals" (IPCC 2006 Vol. 1 Ch. 4). Therefore, a Tier 2 approach may be used because its use **complies with IPCC good practice guidance and guidelines** and may enable a **better quality estimate** of key emission sources from the national inventory. This is because it is expected that accuracy and precision will improve when a higher Tier approach is adopted. It is also possible, however, that uncertainty is not significantly reduced by a Tier 2 approach. This is because the Tier 2 approach makes the quality of data more transparent, so a Tier 2 approach can be useful **to identify better priorities for future improvement.**

Countries can also choose to use a Tier 2 approach. Many countries have included livestock emissions in the scope of their NDC. A Tier 1 approach is not able to reflect the effects of mitigation policies and measures on livestock emissions. Therefore, countries may adopt a Tier 2 approach because it enables the national GHG inventory to **meet national policy objectives**. This will also improve the ability of the country to **report on its progress in achieving NDC targets**.

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Methodological Focus A.3: Potential benefits and limitations of a Tier 2 approach

Using a Tier 2 approach in a national GHG inventory can have several benefits:

- Where livestock emissions are key sources in a national inventory, Tier 2 approaches can more accurately estimate emissions from livestock emission sources.
- Tier 2 approaches better reflect national circumstances and the actual production systems within a country.
- Tier 2 approaches provide more detail on production systems, and this information can be used to identify a range of mitigation options in the livestock sector.
- Tier 2 approaches can better capture changes in emissions due to changes in livestock sector structure, management and productivity. Tier 2 approaches are therefore useful for measuring and reporting progress in achievement of NDCs. Where countries intend to implement mitigation actions in specific livestock sub-sectors or regions in a country, Tier 2 approaches will be necessary to reflect effects on GHG emissions.
- Tier 2 approaches give a more accurate estimate of GHG emission intensity (GHG emissions per unit of livestock product output), so Tier 2 approaches can enable countries to track trends in emissions intensity as well as absolute emissions. This is useful where countries have set NDC mitigation targets in terms of emission intensity.

- Tier 2 equations can be used for forecasting and scenario analysis. This can help policymakers to make informed decisions on policies and set future emissions targets that are realistic for their country.
- Uncertainty analysis or sensitivity analysis of a Tier 2 inventory can be used to identify which factors have the biggest impact on emissions. This information can be used to target research and data collection so that limited resources are used more efficiently than if research is carried out ad hoc.

However, Tier 2 approaches are more demanding of resources and capacity than the Tier 1 approach. It is possible to set up an initial Tier 2 inventory with limited resources using IPCC default values and expert judgement. However, improvement over time will need better data, which may require investment of human and financial resources. If no improvements are made over time, then the policy value of the Tier 2 inventory may be similar to that of a Tier 1 inventory using country-specific emission factors. Moreover, in terms of its scientific basis, the IPCC equations are based on research primarily conducted in temperate regions, and often on dairy cattle breeds. Their applicability to tropical livestock systems is a continuing topic of research.

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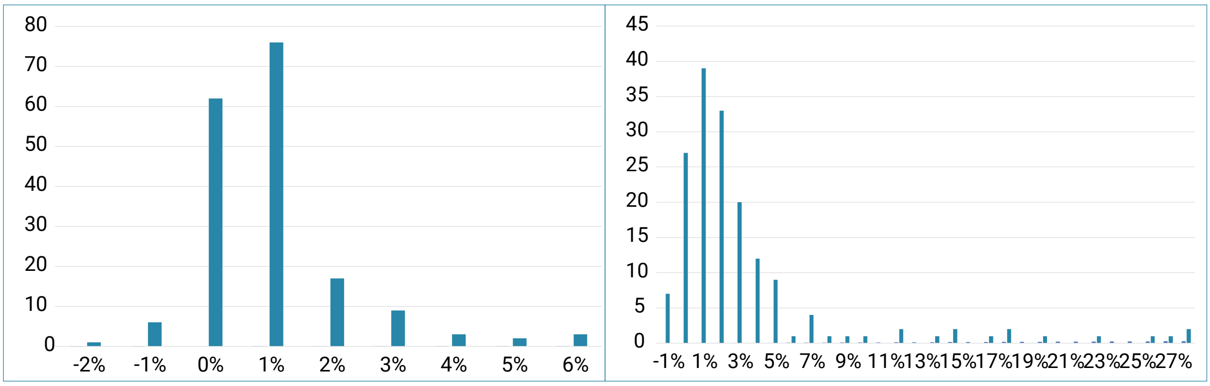
Methodological Focus A.4: Rates of productivity change in the livestock sector

Total livestock emissions may change due to change in livestock numbers, change in the proportion of livestock in different production systems, or change in animal performance and management within a production system. Data from FAOSTAT show that global populations of cattle have been increasing by about 1.5% per year in the last 55 years. Cattle weights have also been increasing by about 2% per year, while cattle milk yields have increased by about 3% per year (**Figure 6**).

Figure 6: Cattle productivity growth rates in 171 countries and regions, 1990-2015



(a) Annual average change in cattle carcass weight **(b) Annual average change in cow milk yield**

Source: FAOSTAT data.

If these average rates of increase in cattle weight and milk yield are applied to the activity data used to develop the IPCC Tier 2 emission factors for cattle in developing regions over a 5-year period, emissions per head would increase by 8% to 13% over this period. Shifting between production systems can perhaps best be represented by a change in feed digestibility. If average feed digestibility increased over 5 years by the same rate as cattle weight and other factors remained the same – increasing from 55% in Africa to 60%, or from 55% to 58% in South Asia – emissions per head would decrease by 20% to 30% over the 5-year period.

While hypothetical, this illustrates that:

- While rates of change in productivity variables are often relatively low, cumulative change over the 5 years of an NDC cycle can have a significant impact on emissions per head;
- It is important to capture changing productivity, if not on an annual basis, at least within a 5-year period;
- Even in the absence of a clear trend in individual animal productivity, tracking change in the distribution of animals between different production systems can be important for capturing the effects on GHG emissions.

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Methodological Focus A.5: The importance of livestock characterization for inventory structure and function

Livestock characterization plays a key role in Tier 2 inventory compilation, because how livestock sub-categories are defined determines the specific data required to compile the inventory. Livestock characterization therefore determines the structure of the inventory and the complexity of activity data collection in future years. Defining animal sub-categories makes it possible to improve inventory detail and help identify mitigation options. The structure of the inventory also determines whether the inventory can track change in the structure of the sector and animal performance. There are two ways in which inventory structure can do this:

1. By categorizing livestock sub-categories so that data on animal performance can be regularly updated, resulting in a changing emission factor for the target sub-category. For example, dairy cows are often a separate sub-group in the inventory. When annual data on milk yields are used in the inventory, the emission factor for dairy cows changes on an annual basis.
2. Tracking change in the distribution of livestock between different categories, resulting in a changing implied emission factor over time. If reliable annual data on productivity are not available, change in management and productivity can be reflected in the inventory using other data. For example, if an inventory separately tracks the number of dairy cows under intensive production (e.g. average daily milk yield of 10 kg) and dairy cows under extensive production (e.g. average daily milk yield of 2 kg), the population weighted average emission factor (i.e. 'implied emission factor') will change as the proportion of dairy cattle in each production system changes.

In these examples, whether dairy cows, or intensive and extensive dairy cows, are explicitly represented as sub-categories of dairy cattle determines whether the inventory is able to track the effects of change over time.

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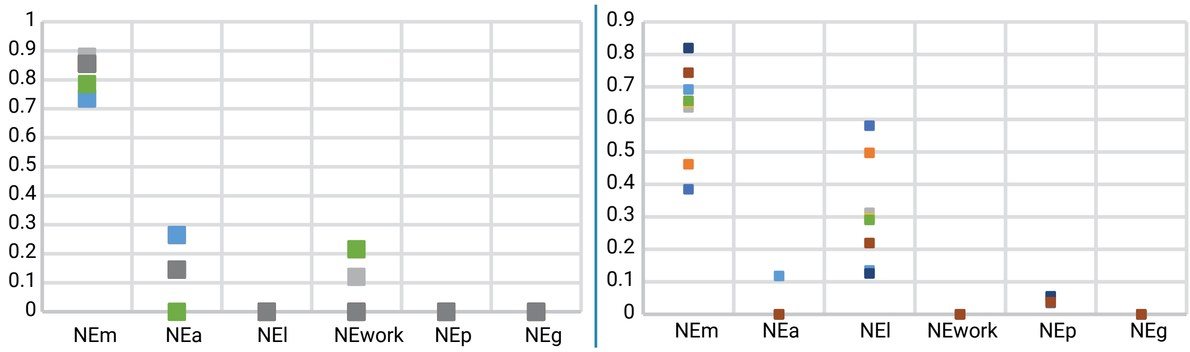
Methodological Focus A.6: Which types of activity data are likely to have the biggest impact on emission factors?

In general, emission factors will vary by level of feed intake and quality of feed. Feed intake per head depends on animal performance (e.g. live weight, weight gain or milk yield). For a given level of feed quality, among animal performance variables, live weight has the biggest impact on emissions for most sheep or cattle sub-categories. This is because the IPCC Tier 2 equations estimate net energy required for maintenance, activity, lactation, pregnancy, work and growth, and for most sub-categories, net energy for maintenance (NE_m) accounts for the majority of energy requirements (Figure 7). For both sheep and cattle, NE_m depends on live weight because the IPCC equation for NE_m is: $NE_m = Cf_i * (weight)^{0.75}$. The exception is for animals with high milk yields, where net energy for lactation (NE_l) can exceed NE_m.

Figure 7: Proportion of net energy requirements from different metabolic functions



(a) adult males, other cattle

(b) dairy cows

Note: The above charts use the IPCC default activity data in IPCC 2006 Annex 10.1

Management also impacts on animal performance and energy requirements. For example, age at slaughter has a strong influence on average live weight and management can affect milk yield. Management also has a strong effect on activity, whether and how animals graze, and their energy requirements. In extensive grazing systems, net energy for activity may account for up to 25% of energy requirements.

Quality of feed will vary significantly between feeding systems, and may vary by animal sub-category (e.g. growing animals bred for slaughter may be fed differently from those bred for reproduction). Therefore, as an initial guide, livestock characterisation should identify sub-categories that reflect significant differences in feeding system, feed quality or live weight. Subsequent sensitivity analysis can be used to identify other factors that the emission factor may be sensitive to.

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Methodological Focus A.7: Will more sub-categories make a more accurate inventory?

A Tier 1 inventory only has one category for each type of livestock. A Tier 2 inventory will have more sub-categories. But will more sub-categories make the inventory more accurate? Let's suppose that a country has two regions and that data is available on animal populations and performance in each region. Figure 8 shows that if the relationship between animal performance parameters and emission factors is linear, then the same result will be obtained if the two regions are calculated separately or if the average value of animal performance parameters is used. In this case, using the average value is as accurate as using two regional values.

However, if the relationship between activity data and emission factors is not linear, and if activity data changes unevenly over time between the two regions, then using the average value may give an inaccurate estimate of later emissions and an inaccurate estimate of the trend in emissions. For example, in Figure 9, "A" indicates a 15% difference between an emission factor estimated using the average digestibility of Regions 1 and 2, and the average emission factor when digestibility is estimated separately for each region. In the short-term, change in animal performance in a production system will happen over a limited range and may be approximated by a linear relationship. The effect of non-

Figure 8: Relationship between milk yield and emission factor

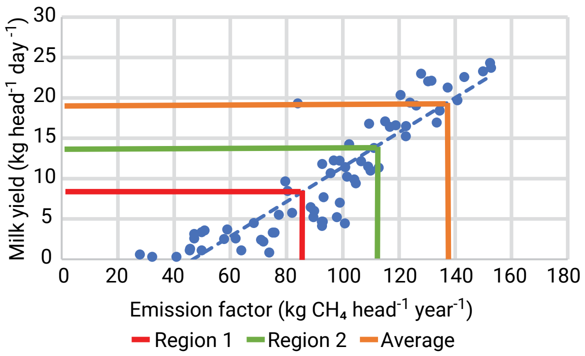
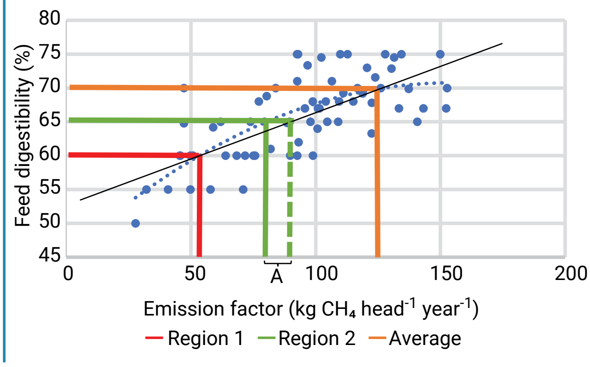


Figure 9: Relationship between feed digestibility and emission factor



linear relationships may be more significant in the longer term. An example is given in a comparison of emissions in New Zealand calculated using a national and a regional approach.

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Methodological Focus A.8: Disaggregating and combining categories

When and how can different animal sub-groups be combined? Take the example of sheep in Mongolia. Official national statistics distinguishes male and female animals. But within male animals, there is no official data on intact and castrated animals. The IPCC Guidelines give different coefficients for intact and castrated males. Should they be represented separately or can they be combined into one 'male' category?

In the IPCC equations, the difference between intact and castrated adult male sheep is reflected in different coefficients for maintenance: Cf_i is 2.17 for castrated males and 2.5 for intact males. If intact males are 5% of the male population, then the population weighted average value of Cf_i for males is (2.17 * 0.95 + 2.5 * 0.05) = 2.19. A single Cf_i value can be used to represent the combined population of intact and castrated males. However, intact and castrated males may have different live weights at maturity, and at younger ages they may have different growth rates. If live weights of intact and castrated males are significantly different, assuming a linear relationship, the population weighted average live weight can also be used to characterize a single category of male sheep. However, if intact and castrated males are fed differently, and if feeding and management of these two categories change significantly over time, a single emission factor for the male group may no longer be accurate.

Take another example: growing male cattle in Kenya's inventory. Sector experts suggested to have 3 categories for growing males: calves 0-1 year, growing males 1-2 years and growing males 2-3 years. The reason for suggesting this was that growth rates vary at each age. However, a research study showed that the growth rate is non-linear until cattle reach puberty around the age of 12 months. After 12 months of age, growth rates are relatively stable. Moreover, there is very little data on specific ages of growing males in the herd. Since male dairy cattle are typically kept for sale as beef cattle, and sales can occur at any age when households need cash, there is significant variation in the actual age of growing males in household herds, and no driver of any systematic trend affecting age at off-take was identified. Therefore, it was decided to combine the 1-2 year and 2-3 year growing male categories, and use available data on the proportion of growing males 1-3 years old in the herd. The live weight and average daily weight gain values used were the averages for growing males of 1-3 years.

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Methodological Focus A.9: Representing geographic or climate regions in livestock inventories

There are several reasons why geographic region may be a relevant criterion for categorizing livestock:

1. Population data often comes from administrative data sources that are collected and reported by administrative area;
2. Regions often have some association with agroecological zone and thus feeding systems;
3. Other activity data (e.g. live weight) are often available by region;
4. Because CH_4 production from manure is influenced by temperature, representing livestock population by climate region is useful to estimate CH_4 from manure management;
5. In some countries, sub-national governments have targets and goals for GHG mitigation, so representation of livestock emissions by region can support national and sub-national policy making.

Characterizing livestock in each region can give a detailed representation of production practices in a country. However, as the 2006 IPCC Guidelines notes, this is only useful if data exists for all regions. Considering also the function of inventories in tracking change over time, representing regions will only be able to track change in emissions if activity data on key management or performance parameters are available in each region on a regular basis.

It is not necessary to represent livestock by regions and many inventories do not do so. In some cases, production systems across a country are sufficiently similar that average animal performance across the country can be used. Regions with similar feeding systems can be grouped together and represented in the inventory as production systems. Production may vary most significantly by farm enterprise type (e.g. smallholder farm, commercial farm) and if data exists on populations in different farm types in different regions, the population in each farm type in each region can be summed across regions. If the distribution of livestock population by region is known, even if they are represented in the inventory as production systems, the population-weighted mean annual temperature can be used to ensure a link with CH_4 manure management emissions.

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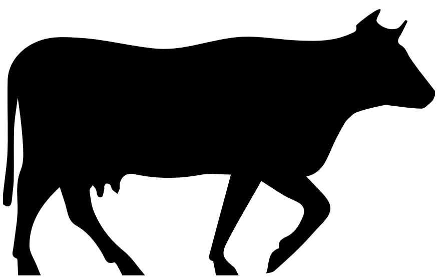

A.5 Worked examples

Worked example A.1: Characterizing activity data for historical periods

The example of feed digestibility estimates in Moldova shows how expert judgement can be used to reconstruct a time series when historical data is missing. Prior to the early 1990s, cattle production in Moldova was organised in collective farms and fodder production was carefully managed. With reforms in the 1990s, the collective farms collapsed and livestock concentrated in the smallholder private sector. The average productivity of dairy cows decreased significantly as fodder production declined. Since the early 2000's, fodder and feed production and dairy cow productivity have improved. Fodder and feed production have also been affected by annual variability in growing conditions, such as droughts or other weather conditions in some years.

For the national GHG inventory, expert judgement was used to estimate the feed digestibility value for cattle in different historical periods. The approach used assumed that when livestock maintenance conditions, fodder and feed production conditions were optimal, the digestibility value would be 67 per cent. Based on changes affecting fodder and feed production and cattle raising in the country, a time series for digestibility was estimated (see Table 4).

Table 4: Cattle feed digestibility values (%) for Republic of Moldova, 1991-2013

Period	1991-1992	1993	1994-1996	1997-2004	2005-2008	2009-2013
Digestibility (%)	68	67	65	66	67	68
Source: Republic of Moldova (2014) National Inventory Report						

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A.6 Additional resources

IPCC Guidance:

IPCC (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

IPCC (2006) Vol. 1 Ch. 4 Methodological Choice and Identification of Key Categories

IPCC (2006) Vol. 1 Ch. 5 Time Series Consistency

IPCC (2006) Vol. 4 Ch. 10 Emissions from Livestock and Manure Management.

Links between Tier 2 approaches and climate policy:

GRA (n.d.) Livestock development and climate change
Wilkes et al. (2017). Measurement, reporting and verification of livestock GHG emissions by developing countries in the UNFCCC: current practices and opportunities for improvement.
See also explanations at https://www.agmrv.org/knowledge-portal/mrv-in-practice/

Inventory software:

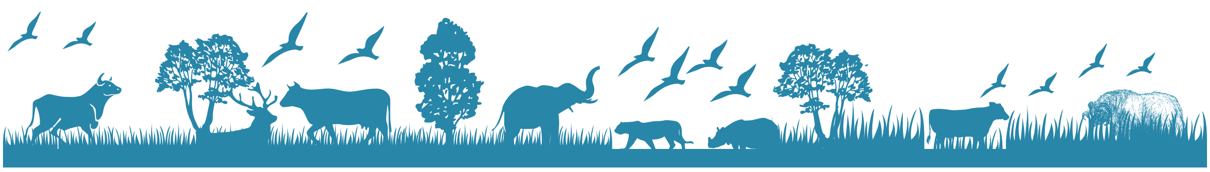
IPCC Inventory Software.

ALU Software.

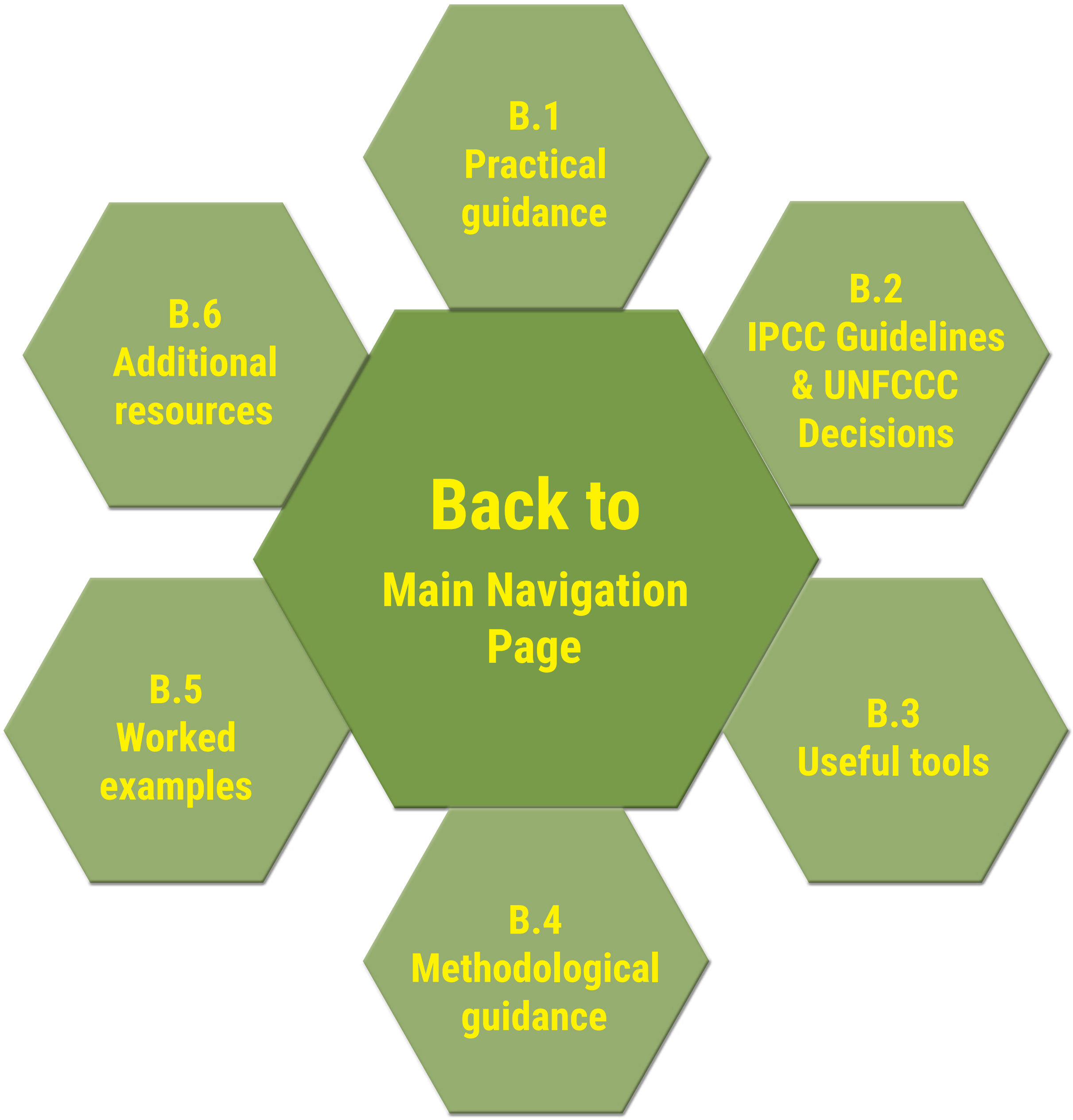
Examples of how to apply the Tier 2 approach:

See case studies of the methods used to compile Tier 2 livestock GHG inventories at https://www.agmrv.org/knowledge-portal/case-studies/

Worked examples of applying the Tier 2 approach are also given in the Handbook on Agriculture Sector produced by the Consultative Group of Experts, which supports developing countries to fulfil their reporting requirements under the UNFCCC. The existing training materials their follow the Revised 1996 IPCC Guidelines, because developing countries are currently not required to use the IPCC 2006 Guidelines. The approach and specific equations in the 1996 and 2006 guidelines are very similar.



B. Assess data availability and quality

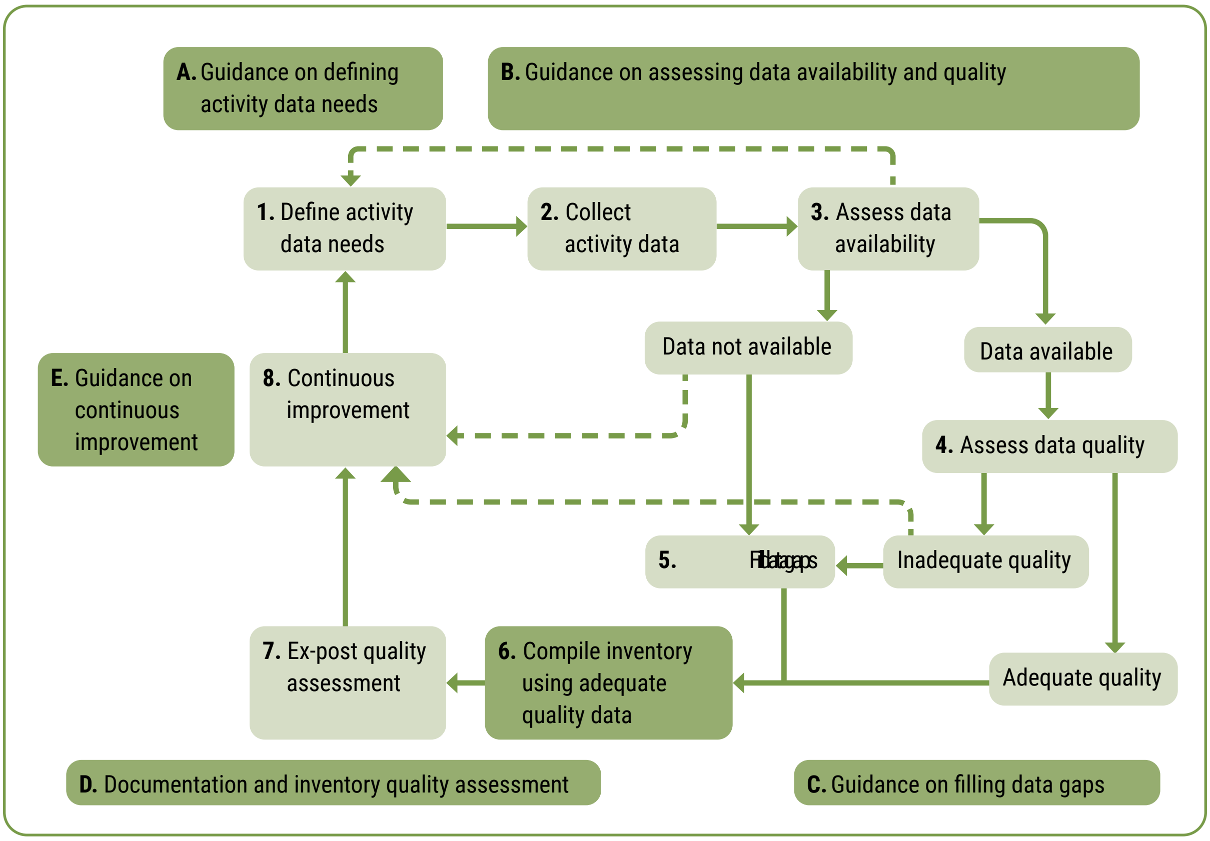


B.1 Practical guidance

Compilation of an initial Tier 2 inventory should aim as far as is practical to meet the data quality objectives of timeliness, transparency, accuracy, consistency, completeness and comparability. However, even in countries with abundant data it will not be possible to fully meet all of these objectives. Recognizing that there are resource limitations for data improvement, the IPCC Guidelines stress that strategies for data collection should lead to continuous improvement over time (see **B.2 IPCC Guidelines & UNFCCC Decisions**). This section provides steps and methods for assessing data availability and data quality, as part of an ongoing continuous improvement process.

Section **B.1.1 General guidance** suggests procedures for how to collect activity data (Step 2 in **Figure 10**); how to systematize activity data to assess data availability (Step 3 in the Framework) and how to assess data quality (Step 4 in the Framework). By following the procedures described, it should be clear which activity data are available; what structure for the inventory is feasible given the available data; and which parameters have data gaps to fill, either because of missing information or because of inadequate data quality. Where data gaps have been identified, values derived from expert opinion or default values in the IPCC Guidelines can be used until country specific data become available. Specific guidance on collecting data required for the IPCC livestock emission equations is given in Section **B.1.2 Guidance for specific parameters**.

Figure 10: Activity data compilation framework



B.1.1 General guidance

When first adopting a Tier 2 approach for livestock GHG emissions, there are few countries where all the necessary livestock activity data are readily available and of good quality. However, in most countries, there is plenty of information that, if systematized, provides a good starting point for compiling an inventory using the Tier 2 approach.
Livestock activity data can be collected and systematized at country level by following a four-step process.

1. Prepare a spreadsheet to record all available livestock activity data
2. Identify the key stakeholders who can potentially supply livestock activity data
3. Collect and record in the spreadsheet all the identified livestock activity data
4. Assess the quality of the available livestock activity data

At the end of this process, it should be clear which activity data are available, and which parameters have data gaps to fill, either because of missing information or because of inadequate data quality.

1 Prepare a spreadsheet to record all available livestock activity data

In order to assess whether existing livestock activity data is sufficient to implement the Tier 2 approach, it is useful to systematically present all available data in one place. There are many different ways to order the available data, depending on the purpose of data collection. At this stage, the main purposes are:

- To decide what inventory structure can be supported by the available data;
- To identify data gaps due to lack of information or data quality gaps.

For these purposes, Tool B.1 (Livestock Activity Data Spreadsheet) suggests ways of organizing activity data in a clear tabular form. Two template options are provided, depending on whether the livestock type has been identified as having undergone change or no change (see Section A How to represent change over time). If the livestock type has been identified as having no change, then the tabular format shown in Table 5 can be used to record available data. If the livestock type has been identified as having changed, Table 6 illustrates a format that can be used to record the availability of data for each parameter in each year in the time series. The spreadsheet version of these templates can be accessed at Tool B.1.

For livestock categories that have not changed, in Table 5 the columns represent the different parameters that need to be estimated, and each row records what information can be found in each data source. The table therefore shows what activity data is available from each data source. It is very unlikely that a single data source can be used to represent all parameters, and it is most likely that different sources have to be used for different parameters. The spreadsheet can also indicate which inventory categories are represented in each data source. These categories will be country-specific and can be adjusted in the template. For example, when it has been filled in, the table can be used to ask: can parameter values be disaggregated by geographic region, production system, breed (or other criterion) to structure the inventory? (see Livestock characterization and inventory structure). In this way, the spreadsheet shows both the availability of data on specific parameters required by the IPCC equations, and the types of inventory category that could be represented using the available data.

Table 5: Livestock activity data spreadsheet when there has been no change

	Categories for inventory structure				Parameters to estimate				
Data source	Year	Production System	Region / District	Agro-eco. Zone	Livestock population	Breed	Body weight	Weight gain	… …
Source 1									
Source 2									
Source 3									
Source 4									
…									
…									
…									

For livestock types that have undergone change, it will be important to collect historical as well as current data in order to assess whether data exists to represent trends over time using a consistent method. Table 6 illustrates a tabular format that can be used to record the availability of data for each parameter in different years. It can also be used to assess whether potential inventory categories (e.g. region, production system) are represented in data from different years.

Table 6: Livestock activity data spreadsheet when there has been change

Year	Parameter 1: Live weight								
	Categories for inventory structure								
	Production Systems			Regions			Agro-eco. zone		
	System A	System B	System C	Region A	Region B	Region C	AEZ 1	AEZ 2	AEZ 3
1990									
1991									
1992									
1993									
1994									
1995	Smith et al 1997			Smith et al 1997					
1996									
1997									
1998		Jones 1999		Jones 1999	Jones 1999				
1999									
2000									
...									
...									

2 Identify the key stakeholders who can potentially supply livestock activity data

The second step is to identify the major stakeholders involved in collection and/or analysis of relevant data. There is very unlikely to be a single dataset that can provide all the necessary livestock activity data. It will be necessary to source information from different datasets and information sources. These will most likely have been created by different stakeholders and for different purposes. Therefore, it is necessary to engage with these stakeholders. Relevant stakeholders may include both public and private actors, farmer and industry organisations, NGOs, research institutions, international organizations and others. **Table 7** presents a list of broad categories of stakeholder who can potentially provide livestock activity data.

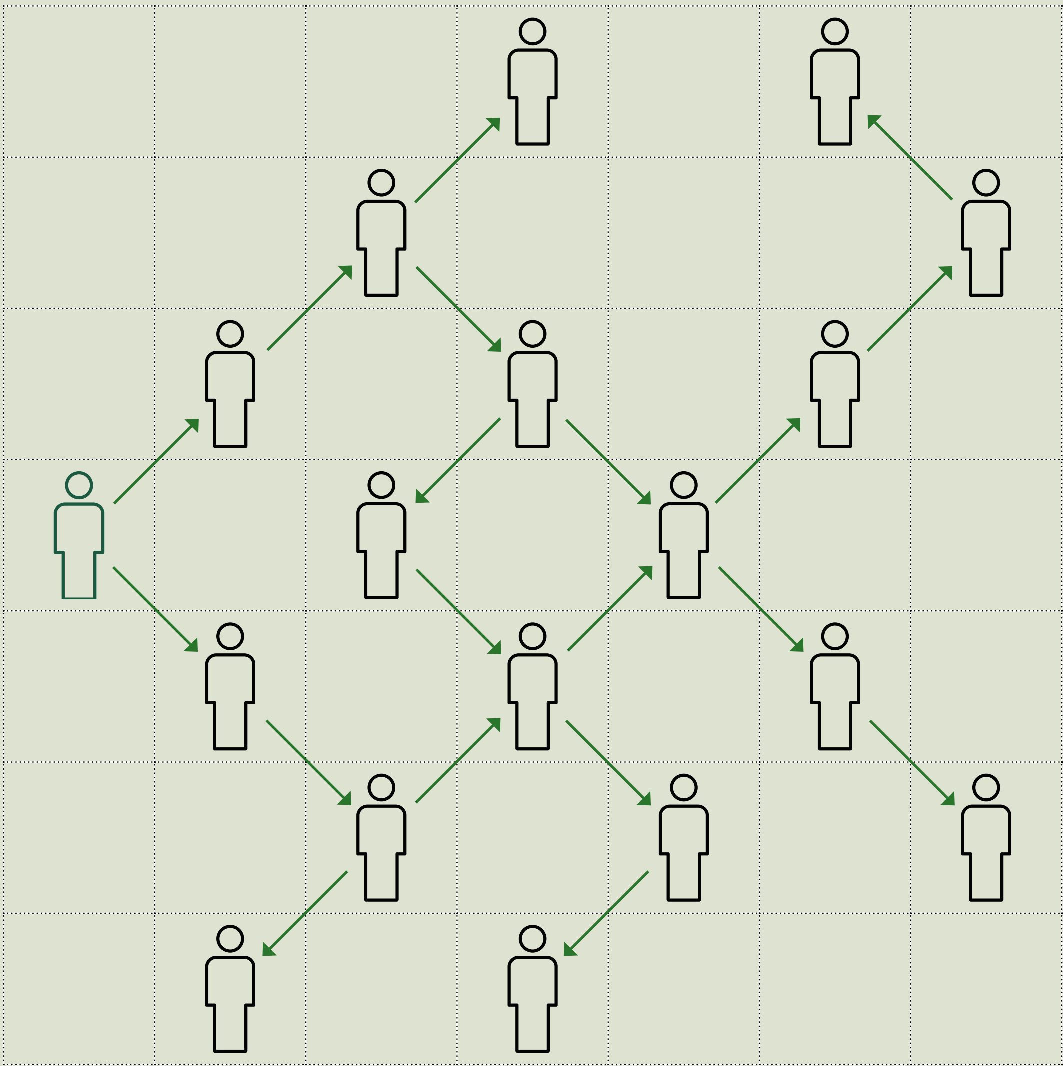
Table 7: Stakeholders with information on livestock activity data

National Statistics Office	The National Statistics Office (NSO) is in most countries the largest independent producer of official statistics. It regularly collects and disseminates data, statistics and reports on a variety of socio-economic domains, including livestock and the environment. The NSO produces statistics following methods and procedures that are in line with the United Nations Fundamental Principles of Official Statistics.
Ministry in charge of livestock	The Ministry in charge of livestock is both a major user and producer of livestock-related data. The Ministry regularly allocates resources to the livestock sector, which involves gathering and utilizing data and statistics. In general, there are three Departments within the Ministry that deal more regularly with data and statistics: the Statistics Department, Monitoring & Evaluation Department, and the Policy and Planning Department.
Ministry in charge of the environment	The Ministry in charge of the environment is a major user and producer of data and statistics, including in some cases livestock-related data. The Ministry directly or indirectly manages public areas such as forests and natural parks, and is responsible for establishing environmental standards, formulating environmental policy, and monitoring its implementation by public and private actors, including livestock sector stakeholders. The Monitoring & Evaluation Unit in the Ministry is responsible for collecting and analysing data, often in collaboration with other public agencies.
Local governments	Many countries are decentralized, with local governments playing a key role in both planning and implementing activities on the ground. These often include livestock-related investments and programmes, for which they might collect and/or use activity data.
Livestock-related statutory bodies	In many countries, there are statutory bodies in charge of establishing and enforcing rules and regulations for specific livestock sub-sectors or commodities. Examples are the Dairy Board and the Meat Board, which release licenses and permits to producers and traders; conduct inspections of milk and meat handling; and perform surveillance on the quality and safety of milk and meat products across the value chain to ensure compliance with relevant standards.
Associations and other industry organisations	Livestock stakeholders often establish Associations, Alliances or Federations aiming to bring together stakeholders in the beef, dairy or other livestock-related sub-sector. These organisations act as platforms to exchange ideas, experience and knowledge and to facilitate dialogue with the government and other stakeholders. In order to formulate their positions on policy issues, these organisations often collect data from members or through surveys.
Livestock operators	Large livestock farms as well as other major public/private operators along the value chain, such as milk processors and slaughterhouses, collect a multitude of data as part of their daily operations, annual budget allocation and investment plans.
Research institutes	Research institutes, including universities, regularly undertake analyses of the livestock sector. This involves examining available datasets and, in some circumstances, collecting data at different nodes of the livestock value chain.
NGOs and civil society organisations	NGOs and other civil society organizations (e.g. cooperatives) implement livestock-related activities on the ground, which requires analysing and, in some cases, collecting activity data.
Donor projects and international organizations	Donor projects – whether implemented directly by international organizations or by the host country government – often collect data, such as baseline survey data and monitoring data, or conduct sector analysis. Some international organisations also maintain datasets that include livestock-related statistics sourced from national governments and/or estimated starting from national data. Several livestock activity data are available in FAOSTAT of the Food and Agriculture Organization of the United Nations (FAO), which provides access to food and agriculture data for over 245 countries and territories.

Table 7 is a starting point to identify actors who might provide livestock activity data. Within each category of stakeholder, there could be more than one actor collecting and/or analysing livestock data. For example, there could be dozens of universities and associated departments or colleges or dozens of NGOs that collect and work with livestock activity data. How to identify all of them?

A practical method is to use a snowball approach, a non-probability sampling technique, to arrive at a comprehensive list of stakeholders that might provide livestock activity data (see Figure 11). The snowball technique involves two steps. The snowball technique involves two steps. The first requires a desk review to identify the key stakeholders who are known to collect and/or analyse livestock activity data or who are known to undertake activities or research on livestock and climate change. The second step is to contact those stakeholders and ask them to list the major actors they are aware of that collect and/or analyse livestock activity data or work on livestock and climate change. By so doing, the list of stakeholders grows like a rolling snowball. The aim is to arrive at a number of stakeholders that is comprehensive enough to ensure that no

Figure 11: Snowball approach to identify stakeholders



major sources of information have been missed. It is impossible to say in advance what a "comprehensive" number of stakeholders is. The only rule of thumb is to arrive at a number that is manageable both in terms of workload and budget. If the list becomes unmanageable, one can apply filters (e.g. years of activity in the livestock sector, geographic areas of operation) or start contacting a small sample of stakeholders and expand the sample opportunistically when livestock activity data and information gaps are identified.

Depending on the resources available, one can consult stakeholders one or more times, individually or through workshops. Further engagement of stakeholders in data sharing may require particular institutional arrangements, such as:

- informal arrangements based on personal relationships;
- contracts for data acquisition or provision;
- inter-agency working groups appointed by the ministry responsible for the inventory;
- inventory compilation teams with representatives of key data providers; or
- formal MoUs to enable data sharing.

In some countries, these institutional arrangements are already put in place by government regulations or climate change laws. Further guidance on institutional arrangements for inventory compilation can be found in the UNFCCC Toolkit for non-Annex I Parties on establishing and maintaining institutional arrangements for preparing national communications and biennial update reports.

3 Collect and record in the spreadsheet all the identified livestock activity data

Once a comprehensive set of stakeholders has been identified, the next step is to obtain the datasets or reports summarizing the data (if the original datasets are unavailable). Some primary and secondary data can be obtained from publicly available sources through a desk review. The desk review should consider official documents targeting both livestock and the environment, such as:

- policies, strategies and statistical reports;
- papers published in scientific journals and chapters in books;
- publicly available sources, such as industry reports or statistical bulletins; and
- 'grey literature', such as working papers and reports, project reports, briefs and any other material that are likely to contain livestock activity data.

Once the desk review is complete, it is time to engage other stakeholders to identify and collect the activity data that they can provide. As datasets or reports are obtained, they can be entered into the Livestock Activity Data Spreadsheet (**Tool B.1**), and the original datasets or reports should stored so that they can be properly archived when inventory compilation is complete (see **D.1.3 Archiving**).

In addition to gathering livestock activity data one should try to access the underlying dataset. The parameters in the IPCC equations (see **The IPCC Tier 2 equations and their parameters**) are different from the data itself. The distinction between parameters and data indicators is important and can be useful in dealing with data gaps. For example, the IPCC equations require data on live weight. If there is a known relationship between, for example, live weight and breed, then data on the proportion of animals by breed can be used to estimate live weight. The difference between parameters and data indicators is discussed in **Methodological Focus B.1: The difference between parameters, indicators and activity data**.

Different data are likely to be available in different datasets. **Table 8** summarises major available data sources while **Table 9** gives an indication of the likelihood that each activity data can be generated out of a given dataset (or survey). **Table 9** does not provide an indication of whether data are likely to be available for homogenous sub-categories of animals as there are no standard approaches in this regard. In general, however, survey data should indicate the location of the farms or households interviewed, thereby allowing the use of administrative boundaries or agro-ecological zones as possible criteria to structure the inventory. For further guidance on possible data sources for each of the specific parameters in the IPCC equations, see Section **B.1.2 Guidance for specific parameters**.

In addition to livestock activity data and the underlying dataset, one should also try to access the so-called metadata. Metadata are data that describe the characteristics of a dataset, such as the sample size, the data collection methods, the definitions used and so on. Metadata are useful to assess some of the quality attributes of the activity data (see Step 4 below). Metadata are usually available for large surveys, but not necessarily for small scale data collection exercises, such as those conducted for research purposes.

Once the activity data has been collected and systematized in the Livestock Activity Data Spreadsheet, one can assess:

- **Which potential inventory categories can actually be represented using available data?** Following **Figure 2**, one can assess which suggested inventory categories can be supported by data on both population and animal performance. If none of the suggested categories can be supported by available data, then following that decision tree, the suggested inventory categories can be revised and the available data again screened to see if the alternative categories can be represented.
- **Which parameters in the IPCC equations have available data?** If some parameters do not have available data, it may be possible to fill data gaps using the methods described in Section **C.1.1 Filling data gaps using available data.**
- **Which parameters have sufficient available data to estimate a consistent time series?** For sub-categories that are known to have significantly changed, or where tracking change over time has important policy functions, it is important to inspect the gathered data to see whether there are sufficient data points from different years to estimate a time series. If there are time series gaps, gaps can be filled using the methods described in **Section C.1.1 Filling data gaps using available data**.

Table 8: Major sources of livestock activity data

Source of livestock activity data	Description
National accounts	The National Accounts bring together units and transactions to estimate the level of production, income, consumption, trade and wealth in the country. It includes a module on livestock that measures the contribution of the different livestock sectors to the national economy.
Population census	The population census is the largest statistical operation countries undertake on a regular basis. Implemented every ten years on average on a complete enumeration basis, the population census provides a snapshot of major population characteristics and might include information on ownership of farm animals. Data from commercial agricultural farms are not accounted for in the census.
Agricultural census	Countries implement agricultural censuses every ten years on average on a complete enumeration basis or on a large sample of farmers / farms. The Agriculture Census provides a snapshot of major characteristics of farms and farmers, including information on ownership of farm animals. Additional livestock Information might or might not be collected, depending on country priorities and the importance or value given to the livestock sector.
Livestock census	Livestock censuses are undertaken only by some countries, usually every 10 years. They are implemented on either a complete enumeration basis or on a large sample of farmers / farms. They capture key 'structural' information on livestock farmers and commercial livestock farms, including details on herd size and composition; feeding and watering practices; manure management; milk yield; etc.
Nationally representative survey (for farmers/farms, households, communities and, in some circumstances, for livestock farmers).	Several countries undertake nationally representative surveys, including for agriculture, livestock, households and communities. The information content of the surveys varies by country but, usually, agricultural and livestock surveys collect sufficient information on the livestock sector to estimate with some accuracy major livestock-related variables, such as the number of animals raised in different production systems.
Small sample survey (for farmers/farms, households, communities and, in some circumstances, for livestock farmers).	Small sample surveys are usually implemented by non-state actors, such as research institutes, NGOs and international organizations, for both research and project purposes. The information gathered varies but, in most cases, is highly detailed, although its external validity or representativeness is often uncertain.
Semi-structured interviews (for farmers/ farms, households, communities and, in some circumstances, for livestock farmers).	Interviews with local actors, such as focused-group discussions with farmers, are ad hoc and rarely part of any systematic livestock data collection infrastructure. Qualitative information is gathered on a variety of items, such as the type of animal breeds, though quantitative information can also be obtained, such as on fertility rate and animal live weight.
Administrative records	Administrative records are data collected by government frontline officers for both performing their duties and M&E. The type of data collected depends on the institutional mandate and structure of the organization responsible for data collection. While often quantitative data are collected on animal numbers and diseases, feed-related information is often qualitative.
Expert opinion	Expert opinion, such as those elicited through expert elicitation protocols, represent a key source of information for parameters / variables that are difficult to measure with accuracy through surveys / interviews, e.g. if farmers have little understanding of the issue investigated, such as the amount of digestible energy in feed.
Field / laboratory measurements	As part of the implementation of specific activities either in the field or in lab, data are generated through direct measurement. Such measurements rely upon the use of specific instruments - such as a weight scale or a lab test - to quantify the value of specific indicators. They are particularly useful to estimate parameters for which it is otherwise challenging to generate an accurate value.

Table 9: Livestock activity data and data sources

	National accounts	Human pop. census	Agric, census	Live-stock census	Nationally repr. agricul-tural survey	National-ly repr. livestock survey	Small sample agric. survey	Small sample livestock survey	Semi-struc-tured inter-views	Admin. records	Expert opinions	Field / laboratory measures
Animal population	++	+	++	++	+	+	-	-	-	+	-	-
Body weight	++	-	+	+	+	+	+	+	+	+	+	+
Mature weight	-	-	-	-	-	-	+	+	+	-	+	+
Weight gain	-	-	-	+	-	+	-	+	+	-	+	+
Body weight at weaning	-	-	-	-	-	-	-	+	+	-	+	+
Body weight at 1 year old	-	-	-	-	-	+	-	+	+	+	+	+
Lamb weight gain	-	-	-	-	-	-	-	+	+	-	+	+
Milk yield	++	-	+	+	++	++	+	++	+	+	+	+
Fat content of milk	-	-	-	-	-	-	-	-	-	-	+	+
% of adult females pregnant	-	-	-	+	-	+	-	+	+	+	+	+
Number of births	-	-	-	+	-	+	-	+	+	+	+	+
Feeding situation	-	-	-	+	-	+	-	+	+	+	+	+
Hours worked	-	-	+	+	+	+	-	+	+	+	+	+
Wool production	+	-	-	+	+	+	+	+	+	+	+	+
Digestible energy as % of gross energy	-	-	-	-	-	-	-	-	+	-	+	+
% of manure managed	-	-	-	-	-	+	-	+	+	-	+	+

KEY "++" likely; "+"possible; "-"very unlikely / no

4 Assess the quality of the available livestock activity data

Quality is a multidimensional and subjective attribute. It is defined by the International Organization for Standardization (ISO) as *'the totality of features and characteristics of a product or service that bears on its ability to satisfy stated or implied needs'* (ISO No 8402; 1986, 3.1). Therefore, users' needs and priorities define quality. IPCC (2006) Vol.1 Ch. 1 identifies five quality characteristics of national GHG inventories:

Transparency: "*There is sufficient and clear documentation such that individuals or groups … can understand how the inventory was compiled and can assure themselves it meets the good practice requirements for national greenhouse gas emissions inventories*".

Accuracy: "*The national greenhouse gas inventory contains neither over- nor under-estimates so far as can be judged. This means making all endeavours to remove bias from the inventory estimates*".

Completeness: "*Estimates are reported for all relevant categories of sources and sinks, and gases. Geographic areas within the scope of the national greenhouse gas inventory are recommended in these Guidelines*".

Consistency: "*Estimates for different inventory years, gases and categories are made in such a way that differences in the results between years and categories reflect real differences in emissions*".

Comparability: "*The national greenhouse gas inventory is reported in a way that allows it to be compared with national greenhouse gas inventories for other countries*".

To ensure these quality attributes are met, the underlying livestock activity data should also be of good quality. The approach to quality assessment set out here is based on the IPCC principles for inventory quality; the UN National Quality Assurance Framework, which suggests a number of principles and practices countries should adopt to ensure good quality data; and the FAO Statistics Quality Assurance Framework, which has a specific focus on agriculture.

Quality assessment involves two steps. The first step is to assess the quality of the dataset, and the second step is to assess the quality of the activity data at hand. **Table 10** presents criteria to assess the quality of a dataset from which livestock activity data is sourced. These criteria combine the IPCC principles with common key criteria for statistics quality assurance. Because the definitions in the table describe the criteria for assessing the **quality of data** used in the inventory, the wording differs from the description of the criteria for **inventory quality** given by the IPCC. The two sets of definitions are, however, compatible.

Table 10: Criteria for quality assessment of a dataset

Transparency	There is sufficient documentation available to understand how the data were collected, including, e.g. information on the sample size, availability of the data collection instrument (e.g. questionnaire), and information on how the data were processed before dissemination (e.g. outlier detection and treatment).
Accessibility	Accessibility is defined as the ease of obtaining the data. This is an important dimension as is assists in identifying data sources that can be easily accessed for estimating GHG emissions.
Completeness	The extent to which the dataset can be used to estimate the activity data required, i.e. the data source describes all items contained within the concepts as defined in the inventory and IPCC guidelines. It is less challenging to source data from a limited number of datasets, which also reduces the need to examine comparability and consistency across different datasets.
Consistency & comparability	The variables estimated and their units are consistent with those required by the IPCC Guidelines. This avoids the need to manipulate the data to estimate the parameters required in the IPCC equations. If two datasets are both consistent, then they are comparable and can be easily combined.
Accuracy - sampling	The accuracy of a statistical output is the degree to which the data correctly estimate or describe the quantities or characteristics they are designed to measure. The sample size and the sampling methods are two elements to consider in order to assess whether the dataset can generate accurate estimates.
Accuracy – non sampling	Accuracy also depends on the use of appropriate methods to collect as well as to process the data, such as the use of methods to prevent and reduce errors in data entry and the implementation of quality checks.
Timeliness	Timeliness indicates whether the information is available when it is needed. In the case of activity data, it can be interpreted to the annual frequency of data availability. For example, annual activity data would allow regular updating of the inventory estimates.

A dataset that satisfies these criteria is likely to generate good quality activity data. Note that the transparency criterion is of paramount importance, because only when all background information about data collection and dissemination is provided can one easily assess the other quality dimensions. Documentation and archiving of all relevant information are important, as discussed in Section **D. Documentation and inventory quality assessment**. In many cases, neither the original dataset nor the background documentation is available. For example, many historical data are only available from published reports. In this case, one should make an effort to go through the reports to gather sufficient information to provide a score against these quality criteria. **Table 11** provides a template to enable scoring of the quality of datasets. The Table is available in spreadsheet form in **Tool B.16**. In that tool, quality is subjective, and the template uses a simple score from 1 to 4 to indicate quality, with the following scores: 1 = there are major issues; 2 = there are moderate issues; 3 = there are minor issues; 4 = there are no issues. Scoring the quality of available data sources can assist in selecting which data sources to use, and ensures that inventory compilers are aware of the characteristics and limitations of each data source. In this scoring system, there is no minimum score below which a dataset cannot be used. If parameter values are available from more than one dataset are available, the higher scoring dataset should be used. The process of scoring may also highlight limitations of available data, and inventory compilers should use their own best judgement to decide whether to use each dataset. The use of this tool in identifying priorities for continuous improvement is discussed in **E. Continuous improvement**.

Table 11: Livestock activity data quality assessment template

Data source	Transpar.	Accessib.	Complet.	Consistency / comparab.	Accuracy sampling	Accuracy non sampl.	Time-liness	Is the dataset usable?
Source 1								
Source 2								
Source 3								
Source 4								
…								
…								
…								

1 = major issues; 2 = moderate issues; 3 = minor issues; 4 no issues

Assessing the quality of a dataset is, on its own, not sufficient to appreciate whether activity data can be accurately estimated using the dataset.

First, most available data were not collected specifically to provide data for the GHG inventory. This means that sampling frames may not be fully representative of the categories used in the inventory. For example, if the inventory defines ‘extensively grazing cattle’ as an inventory sub-category, it may be that data on extensively grazing cattle are available from a large national dataset, but the sampling does not 100% coincide with the population of extensively grazed cattle. This may mean, for example, that sample size may not be sufficient to adequately represent a particular parameter for a given category. For example, take a sample of 500 rural households in a typical Sub-Saharan African country. Only about one third (i.e. 150 households) are anticipated to keep cattle, and of these only about 5 percent will keep exotic breeds of cattle (i.e. a total of 7.5 households out of 500 households). In this example, the sample is clearly not large enough to estimate activity data for exotic breed cattle. Gathering information on the number of observations, therefore, is important to appreciate whether the activity data is estimated from a sufficiently largely sample to be usable.

Second, the gathered livestock activity parameters could have been estimated starting from noisy data, i.e. raw data that included a lot of inaccurate information. This could occur when the activity data parameter originates from non-livestock surveys and the data cleaning process has mainly targeted a core set of variables. A basic quality check on data quality can be made by generating summary statistics, including the average, the median, the mode as well as their confidence interval (see **Methodological Focus B.2: Summary statistics and confidence intervals**). Furthermore, assessing the uncertainty of an inventory is a necessary step. For this, the mean and standard deviation are very useful summary statistics. If data are only available in a report, with no access to the original dataset, it is important to assess whether the mean value is reported together with the standard deviation (or standard error and sample size). This indicates whether the data is amenable to uncertainty analysis. If the mean and median are both reported, they can be compared to assess whether the data fit a normal distribution or not.

Finally, even though the livestock activity data may be statistically sound (e.g. they show a normal distribution), they could be centred around an implausible measure of central tendency. This may occur if the data has been collected and processed by a non-livestock specialist or if the data was collected using an inaccurate method. For example, questionnaire surveys, which rely on farmer responses, may not provide accurate estimates of some livestock activity data, such as live weight or calving rates. Before using any activity data, therefore, it is recommended to consult stakeholders to assess the plausibility of the data, compare it with other available activity data, and gauge any differences with the IPCC default parameters.

Section **IPCC guidance on collection of livestock activity data** discusses some of the data quality problems that are common for the specific activity data parameters used in the IPCC equations.

By systematically assessing the quality of each data source and estimated parameter values against the criteria for quality described above, it should be possible to identify which data are of sufficient quality to use. There will often be trade-offs between the different quality criteria. For example, a dataset may be transparent and consistent, and use an appropriate sampling method, but it may contain data using units or definitions that are not fully aligned with the IPCC parameter definitions. Inventory compilers should use their best judgement in assessing whether a quality weakness makes the data too unreliable to use. In general, quality will not be possible to assess if the methods used to collect the data are not transparently described. If all the available data sources for a given parameter are of poor quality (as scored against one or other quality criterion), the inventory compiler may decide that even though data values exist, it is better not to use the data, but to identify that parameter as having a data gap.

B.1.2 Guidance for specific parameters

The 2006 IPCC Guidelines provides limited specific guidance on the collection of data for the Tier 2 livestock equations. That guidance is summarized in **B.1.2 Guidance for specific parameters**. This section provides further guidance on possible data sources for the key parameters in the IPCC equations and highlights common data quality issues. The following give links to sub-sections on each of the following parameters:

Livestock population and sub-populations

Livestock population and sub-populations

Milk yield, milk fat content and wool production

Feed composition and digestibility

Percentage of females giving birth

Feeding situation and livestock activity

Manure management systems

Livestock population and sub-populations

Tool B.2 gives a list of potential sources of data for total livestock populations and populations of livestock sub-categories. Common sources of livestock population data are census data, administrative data and sample surveys collected by the national statistical agency and/or the ministry of agriculture. Industry organisations may also have databases with livestock population data for their sector. National data from statistics or agriculture agencies will often be available annually. However, a complete and consistent time series may not always be available. Common issues faced include:

- **Time series data gaps:** Censuses are conducted every 5 or 10 years. If a census is the main livestock population data source, there will be data gaps for the years between each census. If there are data gaps, time series gap filling methods can be used (see **C.1.1 Filling data gaps using available data**).
- **No data on populations of livestock sub-categories:** Census or administrative data often only provide total population numbers with no data for populations of each sub-category. If there is only total population data, additional data on herd structure will be needed to estimate populations of sub-categories. If data on herd structure is not given by the sources listed in **Tool B.2**, additional sources listed in **Tool B.3** can be consulted. Further guidance on estimating sub-category populations using additional data sources, including worked examples, is given in Section **C.1.1 Filling data gaps using available data**.
- **Inconsistent data sources:** The categories used or data collection methods may have changed over time. **Worked Example B.7: Aligning livestock sub-category definitions for a consistent time series** gives an example of the methods used to create a consistent time series when the livestock categories quantified in national statistics varied in different historical periods.
- **Estimating annual average populations:** **Methodological Focus B.3: When do I need to estimate the number of days alive for a livestock sub-category?** explains when it is necessary to calculate the annual average population alive. Fattening cattle, small ruminants, pigs and poultry may live for less than a year, but most population data sources do not indicate the number of days alive. To estimate annual average populations, additional data on days alive will be needed. Potential data sources for number of days alive are listed in **Tool B.4**. Literature and industry experts may refer to number of days alive as 'length of the production cycle' or 'age at slaughter'.

Live weight, mature weight and weight gain

The weight related data required to estimate emissions from cattle and sheep differ slightly (**Table 12**).

- For cattle and sheep, annual average live weight (kg) is required for each sub-category. Live weight is used to estimate net energy for maintenance for both cattle and sheep (IPCC 2006 Equation 10.3) and net energy for activity for sheep (IPCC 2006 Equation 10.5).

Additionally:

- For cattle, average daily weight gain (WG, kg per day) and mature weight (kg) are required to estimate energy required for growth (IPCC 2006 Equation 10.6).

Table 12: Weight related parameters for cattle and sheep

	Cattle		Sheep	
	Adult cattle	Young cattle	Adult sheep	Young sheep
Live weight	✓	✓	✓	✓
Average daily weight gain	✓ (or can assume weight gain = 0)	✓	× (assume weight gain = 0)	×
Mature weight	✓	✓	✓	×
Weight at birth	×	×	×	✓
Weight at weaning	×	×	×	✓
Weight at 1 year or slaughter	×	×	×	✓

- For young sheep, data on live weight at weaning and one year of age (or live weight at slaughter if lambs are slaughtered at less than one year of age) are needed to estimate net energy for growth (IPCC 2006 Equation 10.7). If there is no data on sheep milk yield, data on live weight at birth and at weaning can be used to calculate weight gain between birth and weaning for use in estimating net energy for lactation for ewes (IPCC 2006 Equation 10.10).

Live weight: IPCC (2006) suggests that live weight data should be obtained from representative sample studies or existing statistical databases. Potential sources of data on live weight are listed in **Tool B.5**. Sample survey results and statistical databases are potential sources of data that use direct measurements of live weight. If there are no representative datasets, alternative sources of estimates may include feed standards, slaughter weight data and expert judgement by livestock scientists or industry experts. When assessing the suitability of different data sources, common issues include:

- **Representativeness of statistical databases:** Industry organisations or public agencies in many countries have long-term data collection programmes, often aiming to support genetic selection. Data may be collected on livestock characteristics (e.g. live weight), production (e.g. milk yield) and reproduction (e.g. calving rates) from a selection of farms. In some countries, monitoring data is only collected from more commercially-oriented or large-scale farms, and may not adequately represent all production systems (e.g. smallholder livestock keepers). **Methodological Focus B.7: Using animal recording databases** discusses when these databases may or may not be suitable to use.
- **Use of slaughter weight data:** IPCC (2006) cautions that slaughter weight data should not be directly used in place of live weight data. To convert slaughter weight to live weight, data on dressing percentage is also needed (see **Methodological Focus B.6: Using slaughter weight to estimate live weight** to estimate live weight). Slaughter weight is a parameter commonly used in national accounts to estimate the contribution of meat production to the economy. **Methodological Focus B.8: Technical coefficients in national accounts** discusses some issues related to using technical coefficients from national accounts.
- **Lack of consistent time series:** Often, data on live weight will be available from surveys conducted in specific years, but a time series of nationally representative live weight

measurements will not be available. If more than one data point is available, interpolation may be suitable. Or, it may be possible to use surrogate data to estimate a trend in live weight. For example, if there is a known relationship between live weight and breed, or between live weight and feeding system or farm scale, then the time series of data on breed, feeding system or farm scale may be used to estimate a time series for live weight. Guidance on interpolation and use of surrogate data is given in Section **C.1.1 Filling data gaps using available data**.

- **Lack of data on some sub-categories:** Often, direct measurements will be available for some animal sub-categories (e.g. productive females, calves or lambs grown for slaughter), but not for all sub-categories. In this case, it may be possible to estimate live weight for the remaining animal categories by extrapolation from the available data. Methods for estimating live weight using limited available data are discussed in Section **C.1.1 Filling data gaps using available data**, with a specific example in **Worked example C.2: Using 'rules of thumb' to estimate live weights**.

If no data is available from any of these sources for cattle, inventory compilers can also consult the live weight values in IPCC (2006) Annex 10A.1. The tables in that Annex show the live weight estimates used to calculate the IPCC Tier 1 default emission factors for each continental region. National inventory reports and submissions to the UNFCCC by other countries can also be consulted to see if there are estimates for similar animal sub-categories raised under similar conditions (see **B.6 Additional resources**). When basing estimated values on these sources, inventory compilers should justify why the chosen value is appropriate.

Mature weight: Mature weight is the live weight when skeletal development of the animal is complete. Mature weight varies between small and large breeds and between females, and intact and castrated males. The age at which an animal is considered mature may vary between breeds (e.g. early and late maturing breeds). For cattle, IPCC (2006) indicates that the body weight measurement used should be 'shrunk body weight' (SBW), i.e. body weight after 14-16 hours of fasting. SBW is often estimated from live weight by multiplying by 0.96 (see NRC 2000, NRC 2001). For sheep, the standard reference weight (i.e. live weight of a mature sheep with no fleece) may be used.

Tool B.6 lists potential sources of data on mature weight. If the age at maturity is known, then datasets that contain both live weight and age data can be used to estimate mature weight for different animal sub-categories. Scientific publications, or breed characterisation studies, may report estimates of mature weight, or data on weight at different ages from which mature weight can be estimated. Because farmers sometimes consider mature weight when selecting breeding animals, livestock breeders and industry experts may also be able to provide mature weight estimates based on expert judgement. If no data on mature weights is available, it is worth noting that the IPCC Tier 1 default values (IPCC 2006 Annex 10A.1) were estimated by assuming that the weight of mature cattle is the same as the average weight of adult cattle.

Weight gain: For cattle and adult sheep, the IPCC equations require data on average daily weight gain (kg) for each sub-category. IPCC (2006) states that weight gain for mature animals may be assumed to be zero. However, definitions of adult animal sub-categories may include animals of younger age that have not reached skeletal maturity. In this case, it might be more accurate to include an estimate of weight gain for mature animals (see **Worked Example B.4: Whether to estimate weight gain for dairy cows**).

Tool B.7 lists potential sources of data on weight gain. When identifying these data sources it is important to ensure that the data are representative of the animal sub-category as defined in the inventory. In many countries, reports of weight gain estimates are more common for commercially-oriented farming systems, and may not be representative of other farming systems (e.g. smallholders, pastoralists).

For lambs, the IPCC equations also require data on live weight at weaning (BW_i) and live weight at one year old or at slaughter (BW_f), if slaughtered prior to one year of age. Potential data sources for these parameters can most likely be obtained from the same types of data sources listed in **Tool B.7**. Where direct estimates of weight gain or lamb live weights at weaning and one year old are not available, but data on live weights of adult animals is available, then methods described in **C.1.1 Filling data gaps using available data** may be useful to estimate weight gain or lamb weights at different ages. In addition, for cattle, inventory compilers can consult the weight gain values in IPCC (2006) Table 10A.2. That table shows the weight gain values used to calculate the IPCC Tier 1 default emission factors for 'other cattle'. National inventory reports and submissions to the UNFCCC by developing country parties can also be consulted to see if there are estimates for similar animal sub-categories raised under similar conditions (see **B.6 Additional resources**). When basing estimated values on these sources, inventory compilers should justify why the chosen value is appropriate.

Milk yield, milk fat content and wool production

Milk yield: The milk related data required to estimate emissions from cattle and sheep differ slightly:

- For cows, net energy for lactation is estimated based on milk yield (kg) and milk fat content (%) (IPCC 2006 Equation 10.8). Milk yield should be estimated in kg per head per calendar day.
- For adult female sheep (i.e. ewes), only data on milk yield (kg $head^{-1}$ day^{-1}) is required (IPCC 2006 Equation 10.9).
- If a Tier 2 approach is also applied to nitrous oxide emissions from manure management, data on crude protein content of milk (%) is also needed to estimate nitrogen intake (IPCC 2006 Equation 10.32).

Milk yield per head may be estimated using either a 'top-down' or 'bottom-up' method:

- A 'top-down' method uses data on total national milk output, which is divided by number of cows in milk to derive an estimate of average annual milk production per head. Annual milk production per head is then divided by 365 to estimate average daily milk yield per cow. Adjustments can be made for milk consumed by calves and for home consumption by dairy farmers. This 'top-down' method is more suitable when (a) the majority of milk is marketed through formal channels and national milk output data are reliable, and (b) the GHG inventory includes only one category of milking animal.

- A 'bottom-up' method uses direct estimates of milk yield per cow or per ewe.

For both methods, it is possible that milk yield estimates do not include milk consumed by calves. It may therefore be necessary to adjust per head milk yield estimates to account for milk consumed by calves before they are weaned. Calf milk consumption may either be estimated from surveys of calf rearing practices or estimated on the basis of net energy requirements. For example, NRC (2001) Table 10-1 provides methods to estimate net energy intake by calves for maintenance and for growth based on calf live weight and live weight gain, which can be converted to kg of milk based on the energy content of milk (see **Worked Example B.8: Estimating calf milk consumption using the NRC method**).

Tool B.8 lists potential data sources on total national milk output, and **Tool B.9** lists potential data sources on milk yield per head. Data on sheep and gaot milk production are less common than for cow milk. Possible data sources for sheep and goat milk yields include industry organisations and producers, breeding or value chain development programmes, scientific publications or dairy sheep or goat experts. Where no data on sheep or goat milk yields are available, IPCC (2006) Equation 10.10 provides a method for estimating net energy for lactation on the basis of lamb weight gain from birth to weaning.

When assessing available data on milk yield, common issues to consider include:

- **Concepts and units:** Reported milk output and milk yield may or may not include calf consumption and home consumption by livestock keepers. If they are not included, when using the top-down milk yield estimation method, it may be necessary to obtain data from surveys or other sources to estimate the volume of milk not marketed. Milk output and milk yield are often reported in litres. The IPCC equations require an estimate of average daily milk yield in kg. Litres can be converted to kg by multiplying litres by 1.031. In scientific and other reports, reported milk yield per head is often the milk yield per lactation, but cows may not lactate for 365 days per year. If lactation duration is less than 365 days, lactation milk yield can be converted to an annual daily value using the following equation:

$$Milk = MY_{daylac} \times \left(\frac{Days_{lac}}{365}\right)$$

where

Milk is kg of milk per day

$MY_{day,lac}$ is average daily milk yield during a lactation, kg

$Days_{lac}$ is length of lactation, days.

- **Representativeness of statistical databases:** Many countries have a public or industry agency that is responsible for dairy cattle performance recording. This is often related to national artificial insemination programmes. The recorded data often comes from farms that raise better breeds, and may use management and feeding practices that are not typical of dairy cattle on smallholder farms (see **Methodological Focus B.7: Using animal recording databases**).
- **Lack of consistent time series:** Often, data on milk yield will be available from surveys conducted in specific years, but a time series of nationally representative milk yield measurements may not be available. In these cases, it may be possible to use surrogate

data to estimate a trend in milk yield. For example, if there is a known relationship between milk yield and breed, or between milk yield and feeding system or farm scale, then the time series of data on breed, feeding system or farm scale may be used to estimate a time series for milk yield. Further guidance, including worked examples, for using surrogate data to estimate trends in milk yield is given in Section **C.1.1 Filling data gaps using available data**.
- **Lack of data on some sub-categories:** It may be that direct measurements are available for some production systems (e.g. commercial farms), but not others. In this case, it may be possible to estimate milk yield for the remaining production systems by extrapolation from the available data. Methods for using limited available data to estimate milk yield are discussed in Section **C.1.1 Filling data gaps using available data**.

Average annual milk yield is a parameter commonly used in national accounts to estimate the contribution of the dairy sector to the economy. **Methodological Focus B.8: Technical coefficients in national accounts** discusses some issues related to using technical coefficients from national accounts.

Milk fat and protein content: Milk fat content (%) is used to estimate net energy for lactation for cows, and milk fat and milk protein content (%) are both used in estimating nitrous oxide emissions from manure management using the Tier 2 approach. **Tool B.10** lists potential sources of data on milk fat and protein content. If none of the data sources in **Tool B.10** are available, the IPCC default values (4% fat, 3.5% protein) may be used (IPCC 2006 VOL. 4 Ch. 10, page 10.60).

Wool production: **Tool B.11** lists potential data sources for wool production. If there are no official national data on wool production per head or nationally representative research reports, industry organisations, livestock experts or breeders should be able to provide estimates. FAOSTAT also provides data on wool yields per animal.

Feed composition and digestibility

Feed digestibility is a key input into the IPCC Tier 2 equations for both enteric fermentation (IPCC 2006 Equations 10.15 and 10.16) and methane emissions from manure management (IPCC 2006 Equation 10.24). In the IPCC equations, feed digestibility is expressed as digestible energy as a percentage of gross energy (DE%). Estimating feed digestibility requires information on:
- Composition of diet for each animal sub-category, and
- Digestibility of each feed component in the diet for each animal sub-category.

If the inventory will also estimate nitrous oxide emissions from manure management, information on the average crude protein content of the diet (CP%) will also be required.

There are two main approaches to obtaining information on animal diets:
- **Estimating diet composition based on feed and forage availability:** In this approach, data is obtained on the feed and forage that is available or that is produced. Animal diets are assumed to reflect feed and forage availability. This approach may be more suitable when there is little differentiation in feeding practices among animal sub-categories.

- **Estimating diet composition based on feeding practices:** In this approach, data is obtained on feeding practices, which is then used to estimate diet composition. This approach may be more suitable when different animal sub-categories are fed different diets.

An example comparing the two approaches is given in **Methodological Focus B.9: Estimating feed composition using feed availability or data on feed as-fed**.

Tool B.12 lists potential sources of data on diet composition. **Tool B.13** lists potential sources of data on feed digestibility and crude protein content. Common issues faced when collecting data on DE% include:

- **Definitions and units for digestibility:** In databases and scientific publications, digestibility is often reported as organic matter digestibility (OMD) or dry matter digestibility (DMD). DE% can also be predicted from other nutrient characteristics of feed (e.g. Neutral Detergent Fibre, Acid Detergent Fibre) that are commonly reported in feed nutrient databases and scientific studies. Conversion from these measurements to DE% is discussed in **Methodological Focus B.10: Predicting feed digestibility from other chemical characteristics of feed**.
- **Use of feed and nutrition tables:** Feed tables are often used by producer organisations or extension workers to formulate feed rations and to assess production levels given available feed. Where livestock keepers refer to feed tables in formulating the diets fed to animals, these feed tables may be a suitable source of data on both diet composition and digestibility. In this case, it is assumed that diets fed reflect the contents of feed tables. Where this assumption does not hold, other sources of data on diet composition may be more accurate.
- **Representativeness of data:** Even where data on diet composition is available, it often focuses on milking females or other animal categories. Data may not fully reflect the diets fed to different animal categories. When there are information gaps of this kind, guidance on gap filling can be found in **C.1.1 Filling data gaps using available data**.
- **Lack of a time series on diet composition or feed digestibility:** Change in diet composition over time can be an important factor driving changes in emissions. Methods for filling time series data gaps are given in **Section C.1.1 Filling data gaps using available data**.

If country-specific data on feed composition is available, but there is no data on feed digestibility or CP%, international databases can be useful. In particular, www.feedipedia.org is an online resource that contains feed nutrient values for numerous forage and feed products. If there is no data on diet composition, inventory compilers can consult the default digestibility values presented in IPCC (2006) Table 10.2, Table 10A.1 and Table 10A.2.

Percentage of females giving birth

The percentage of females giving birth is used to estimate net energy for pregnancy. This percentage is often reported in statistical and other sources as 'calving rate', 'lambing rate' or 'fertility'. **Tool B.14** lists potential data sources for the percentage of females giving birth. For sheep, an estimate of single, double or triple births is also required. This is often reported as 'proflicacy' or 'fecundity', i.e. the number of young produced per ewe each year.

Information on number of births per ewe can often be found in breed characterisation studies or can be obtained from industry organisations or livestock experts. For cattle, if there is no available data on the percentage of females giving birth, it can also be estimated from data on calving intervals (see **Worked Example B.5: Estimating the proportion of cows giving birth from calving interval data**). If no data on percentage of female cattle giving birth are available, inventory compilers can consult the default values presented in IPCC (2006) Tables 10A.1 and 10A.2.

Feeding situation and livestock activity

'Feeding situation' is a characterisation of whether animals are confined or grazing, and whether grazing requires limited energy (e.g. in paddocks or flat grazing land) or greater energy (e.g. large or hilly grazing land). The 'feeding situation' is used to select the appropriate value for the coefficient for activity (C_a) in IPCC 2006 Equations 10.4 and 10.5. Default values for the corresponding coefficient are given in IPCC (2006) Table 10.5. In many cases, it is relatively straightforward to determine which feeding situation applies to an animal sub-category and it is sufficient to use the default values for C_a. In some cases, however, the distinction between pasture and grazing large areas is not clear. **Methodological Focus B.11: Calculating an appropriate value for the coefficient for activity.** provides further guidance on how to determine the appropriate feeding situation or value of C_a.

If feeding situation for an animal sub-category does not vary through the year (e.g. 365 days of grazing), then it is relatively straightforward to determine the feeding situation. If feeding situation varies during the year (e.g. by season), it may be necessary to obtain additional data on the number of days spent grazing in the year. A weighted average annual value of C_a can then be estimated (see **Worked Example B.6: Calculating a weighted average activity coefficient**).

Manure management systems

To estimate manure management methane emissions (IPCC Equation 10.23) and direct and indirect nitrous oxide emissions (IPCC Equations 10.25 and 10.26), data is needed for each animal sub-category on the proportion of manure managed in different manure management systems (MMS). For manure management methane emissions, additional information on the mean annual temperature is required to select appropriate values for methane conversion factors (MCF) for each manure management system.

Potential sources of data on manure management systems are listed in **Tool B.15**. In many countries, there have been few studies of manure management systems. Because of the relevance of manure management to agri-environment pollution and to rural energy, manure management surveys may have been undertaken by agencies involved in environment management or rural energy, rather than livestock agencies. In particular, if a country has implemented a national biogas programme, or a Clean Development Mechanism or voluntary carbon market project involving manure as a biogas feedstock, agencies involved in these initiatives may be a source of data on manure management practices. Links to online biogas project registries are given in **Tool B.15**. Common issues faced in identifying available manure management data include:

- **Definition of systems:** Manure management systems reported in surveys may not be categorized in the same way as the IPCC categorization. Because methane conversion factors are given according to the IPCC categories, it will be necessary to align reported categories with the IPCC categories. This can be done using advice from manure management experts.
- **Inclusion of pasture:** In mixed stall-grazing systems, manure management surveys often only document the allocation of manure on-farm between manure management systems. If animals also graze, some portion of manure will be deposited on pasture. It may be necessary to combine different data sources to estimate the allocation of manure between pasture and farm-based manure management systems.

If no data on manure management systems is available from the sources listed in **Tool B.15**, inventory compilers may consult the default MMS values given in IPCC (2006) Annex 10A.2. When consulting the tables in that Annex, inventory compilers should examine the animal and climate characteristics given in the table and select default emission factors for regions that most closely match national circumstances.

Data on mean annual temperature (MAT) can be obtained from national meteorological agencies. If data is not available from national sources, historical climate data can be obtained from online databases (e.g. https://climateknowledgeportal.worldbank.org/ or other online climate data sources). MAT values should be representative of the geographical regions for different categories in the inventory. Obtaining detailed data on MAT is particularly relevant if liquid/slurry, anaerobic lagoons, pit storage or deep bedding manure management systems are used, because the IPCC default MCF values for these systems vary for each °C of change in MAT. IPCC (2006) suggests to estimate the percentage of livestock populations in each temperature zone and compute a weighted average MCF value. If the distribution of livestock by temperature zone is not available, annual average temperature for the whole country can be used.

B.2 IPCC Guidelines and UNFCCC Decisions

IPCC general guidance on data collection

The 2006 IPCC Guidelines (Vol. 1 Ch. 2) identify the following principles underlying good practice in data collection:

- "Focus on the collection of data needed to improve estimates of key categories which are the largest, have the greatest potential to change, or have the greatest uncertainty.
- Choose data collection procedures that iteratively improve the quality of the inventory in line with the data quality objectives.
- Put in place data collection activities (resource prioritisation, planning, implementation, documentation etc.) that lead to continuous improvement of the data sets used in the inventory.
- Collect data/information at a level of detail appropriate to the method used.
- Review data collection activities and methodological needs on a regular basis, to guide progressive, and efficient, inventory improvement.
- Introduce agreements with data suppliers to support consistent and continuing information flows."

Continuous improvement to support improved reporting and transparency is also explicitly encouraged in the Annex to the Modalities, Procedures and Guidelines on transparency of the Paris Agreement (paragraph 7).

The IPCC 2006 Guidelines further stress the importance of maintaining the supply of inventory data by engaging data suppliers through workshops and informal updates, contracts or memoranda of understanding so that:

- links are established with data suppliers;
- data suppliers understand inventory data needs; and
- inventory compilers properly understand the data provided, can assess their quality, and be informed of any changes in data collection and management methods.

The 2019 Refinement to the 2006 IPCC Guidelines further notes that it is good practice to make the following checks on any data collected:

- Is the dataset complete (geographically, covering all the target population and the whole year)?
- Does the data have associated measurement uncertainty information (including information on the shape of the probability distribution function)?
- What assumptions underlie the data (e.g. sampling representativeness)?
- Were reliable measurement methods used?
- Does the dataset include a complete time series?
- Has the collected data already undergone specific QA/QC procedures? Are these procedures documented?

IPCC guidance on collection of livestock activity data

The 2006 IPCC Guidelines (Vol. 4 Ch. 10) gives limited specific guidance on the collection of livestock activity data. In general, country-specific data (e.g. national statistics, industry sources, research studies) are preferred to international data sources (e.g. FAO statistics). The IPCC has published a meeting report describing which parameters required by inventories are available from which FAO datasets.

For livestock population data, if possible, data should come from official national statistics or industry sources. In addition to documenting the annual population estimates, inventory compilers should also document: data sources; data collection methods; any potential areas of bias; estimates of accuracy and precision; and any adjustments made for their use in the inventory and related assumptions. The data should be cross-checked with data for previous years to ensure that population estimates are reasonable and consistent with the expected trend.

For activity data used to derive Tier 2 emission factors, all the data used, including their references, should be fully documented. For several parameters, such as live weight and feed digestibility, the IPCC Guidelines note that it is unrealistic to perform a complete census. Data for these parameters should be taken from representative sample studies, research studies or statistical databases if they exist. For manure management system activity data, the preferred source is national statistics. If these are unavailable, alternatives include surveys and expert opinion.

B.3 Useful tools

This section provides two spreadsheet templates for assessing the availability and quality of activity data and a set of tables describing possible data sources for the key parameters in the IPCC equations. The following table gives links to each tool:

Tool B.1	Templates for livestock activity data spreadsheet
Tool B.2	Potential data sources for livestock populations and populations of livestock sub-categories
Tool B.3	Potential data sources for herd structure
Tool B.4	Potential data sources for number of days alive
Tool B.5	Potential data sources for animal live weight
Tool B.6	Potential data sources for animal mature weight
Tool B.7	Potential data sources for average daily weight gain
Tool B.8	Potential data sources for total national milk output
Tool B.9	Potential data sources for milk yield per animal
Tool B.10	Potential data sources for milk fat and protein content
Tool B.11	Potential data sources for wool production
Tool B.12	Potential data sources for diet composition
Tool B.13	Potential data sources for feed digestibility and crude protein
Tool B.14	Potential data sources for the percentage of females giving birth
Tool B.15	Potential data sources for the proportion of manure managed in different manure management systems
Tool B.16	Template for data quality assessment spreadsheet

Tool B.1: Templates for livestock activity data spreadsheet

These spreadsheets can be used to systematically document activity data sources and identify information gaps. The spreadsheet file contains two suggested templates:

- one for livestock types for which management and performance has not changed over the inventory period. For livestock types that have not changed, data from sources produced in any year can be entered to record potential data sources and identify information gaps.
- one for livestock types for which management and performance has changed. For livestock types that have changed, data sources are entered by year, giving inventory compilers an overview of data availability for constructing a consistent time series for each parameter.

The tool can be downloaded from this external link: https://www.agmrv.org/knowledge-portal/resources/templates-spreadsheets-for-assessing-the-availability-of-tier-2-livestock-activity-data/

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Tool B.2: Potential data sources for livestock populations and populations of livestock sub-categories

Population census	Most countries undertake a population census every ten years on a complete enumeration basis. The population census might include data on ownership of farm animals. Often data is only collected for each livestock type, but data on sub-categories may also be available. Data from commercial agricultural farms are not included in the census.
Agricultural census	Many countries implement an agricultural census every ten years on a complete enumeration basis or on a large sample of farms. The agricultural census may include data on ownership of farm animals, and additional information on populations of sub-categories and livestock management may also be collected if the livestock sector is a country priority.
Livestock census	Some countries conduct a livestock censuses, usually every 10 years, on a complete enumeration basis or on a large sample of farms. This may include both smallholder and commercial farms, and will usually include details on herd size and composition as well as management practices and animal performance.
Nationally representative agricultural survey	Several countries undertake nationally representative surveys for agriculture, livestock, households or communities. These surveys may not be done every year. The information content of the surveys varies by country, but agricultural and livestock surveys are likely to collect data on livestock populations and sub-populations.
Nationally representative livestock survey	
Nationally representative household survey	
Administrative statistics	Ministries of agriculture often collate data annually from each sub-national division (e.g. county, province) on the population of livestock types. Sometimes the data will also show populations of each livestock sub-category.
Industry organisations	National industry organisations (e.g. dairy or meat associations) may have registers of members and may collect data on numbers of farms and animals in their sector. In some cases, this data may only represent part of the commercial sector and may not be nationally representative.
FAOSTAT	FAOSTAT provides data on the total population for livestock of each type. For cattle, the population is not divided between ‘dairy’ and ‘other’ cattle types.

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Tool B.3: Potential data sources for herd structure

Survey reports	Herd structure will often be reported in the results of surveys undertaken for policy analysis or research, and in surveys undertaken by donor projects and NGOs. The survey results are often reported in scientific publications or 'grey literature' published by research institutes, industry associations, donor projects or NGOs. To access the underlying data, it would be necessary to contact the institutions that published the results or the researcher that conducted the survey.
Industry organisations	National industry organisations (e.g. dairy or meat associations) may have data on herd structure. In some cases, this data may only represent part of the commercial sector and may not be nationally representative. Industry association experts may also be a source of expert judgement.
Expert judgement	Where there is limited or no data on herd structure, experts (e.g. livestock scientists, industry experts, livestock ministry officials) familiar with the sector should be able to estimate the typical structure of herds or flocks.

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Tool B.4: Potential data sources for number of days alive

Industry organisations	National industry organisations (e.g. dairy, meat or poultry producers' associations) may have data on age at slaughter or length of the production cycle. In some cases, this data may only represent part of the commercial sector and may not be nationally representative. Industry association experts may also be a source of expert judgement.
Survey reports	Length of the production cycle or age at slaughter will often be reported in the results of surveys undertaken for policy analysis, investment analysis or research purposes, and in surveys on value chain functioning undertaken by donor projects and NGOs. The survey results are often reported in scientific publications or 'grey literature' published by research institutes, industry associations, donor projects or NGOs. To access the underlying data, it would be necessary to contact the institutions that published the results or the researcher that conducted the survey.
Expert judgement	Where there is limited or no data on number of days alive, experts (e.g. livestock scientists, industry experts, livestock ministry officials) familiar with the sector should be able to estimate the typical age at slaughter or length of the production cycle. In addition to experts on livestock production, experts on post-production phases (e.g. slaughter) may also have relevant knowledge.

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Tool B.5: Potential data sources for animal live weight

Sample surveys	Sample survey results may be available in scientific publications or 'grey literature' published by research organisations, industry organisations, donor projects or NGOs.
Statistical databases	Databases containing live weight records are often kept by national livestock recording programmes, breed associations or industry organisations. However, care should be taken to assess whether these databases are representative of the production systems in the inventory. For example, in many developing countries, monitoring data are often collected from more commercially-oriented, large scale farms, that may not be fully representative of small-scale farms.
Feed and nutrition standards	Feed and nutrition standards contain the nutrition requirements of different types of animal. Similar to the IPCC equations, nutrition requirements are based on energy intake requirements, and thus must consider live weight and weight gain alongside other metabolic functions. Where farmers refer to nutrition standards to guide their management practices, these standards can be assumed to be applicable to describing actual farming practices.
Slaughter weight	Some governments collect slaughter weight data for use in calculating livestock sector output and GDP. Slaughterhouses may have data or be able to provide expert judgement on the carcass weight and dressing percentage of livestock.
Expert judgement	Veterinary agencies calculate immunisation doses in ml per kg body weight, and may be able to provide estimates of live weight for different livestock sub-categories. Livestock scientists or industry experts may also be able to provide estimates based on expert judgement.
National accounts	National accounts often use technical coefficients for carcass weight to estimate the contribution of livestock to the national economy. These can be combined with data on dressing percentage to estimate live weight.

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Tool B.6: Potential data sources for animal mature weight

Sample surveys	Sample surveys may be available in scientific publications or grey literature published by research organisations, industry organisations, donor projects or NGOs. If surveys collected data on both animal live weights and age, this may be used to estimate mature weights.
Statistical databases	Databases containing live weight records are often kept by national livestock recording programmes, breed associations or industry organisations, and may be used to estimate mature weights. However, care should be taken to assess whether these databases are representative of the production systems in the inventory.
Scientific publications	Scientific publications may report mature weights. However, genetics and management of animals raised on experimental farms may differ from conditions in other production systems.
Expert judgement	Veterinary agencies calculate immunisation doses in ml per kg body weight, and may be able to provide estimates of live weight for different livestock sub-categories, including mature animals. Livestock scientists or industry experts may also be able to provide estimates based on expert judgement.

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Tool B.7: Potential data sources for average daily weight gain

Sample surveys	Data on weight gain may be available from sample surveys conducted by research organisations, NGOs or donor projects. Sample survey results may also be reported in scientific literature or grey literature.
Statistical databases	Databases containing live weight gain records may be kept by national livestock recording programmes, breed associations or industry organisations. However, care should be taken to assess whether these databases are representative of the production systems in the inventory. For example, in many developing countries, monitoring data are often collected from more commercially-oriented, large scale farms, that may not be fully representative of ordinary farms.
Feed and nutrition standards	Feed and nutrition standards contain the nutrition requirements of different types of animal. Similar to the IPCC equations, nutrition requirements are based on energy intake requirements, and thus must consider live weight and weight gain alongside other metabolic functions. Where farmers refer to nutrition standards to guide their management practices, these standards can be assumed to be applicable to describing actual farming practices.
Expert judgement	Where breeds and management practices are relatively uniform (e.g. on commercial farms) direct estimates of weight gain may be available from industry organisations and experts. In more diverse farming systems (e.g. smallholder farms), extension workers working with farmers may also be able to provide estimates based on expert judgement.

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Tool B.8: Potential data sources for total national milk output

Official statistics	Total national milk output may be reported in official statistical reports (e.g. yearbooks, annual reports, statistical databases) by national agriculture or statistical agencies. It is advisable to check the meta-data to understand whether the official data considers home consumption of milk by farmers and milk consumption by calves.
Industry organisations	Industry organisations (e.g. milk processor associations, milk marketing boards) often collect data on milk output. Note that the reported figures may refer to formally marketed milk only, which may be a small proportion of total milk output.
National accounts	National accounts estimate total milk output in order to assess the contribution of livestock to the national economy.
FAOSTAT	FAOSTAT provides estimates of total national milk output for several types of ruminant, as well as estimates of yield per head.

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Tool B.9: Potential data sources for milk yield per animal

Sample surveys	Sample survey results may be available in scientific publications or grey literature published by research organisations, industry organisations, donor projects or NGOs.
Statistical databases	Databases containing milk yield records are often kept by national livestock recording programmes, breed associations or industry organisations. However, care should be taken to assess whether these databases are representative of the production systems in the inventory. For example, in many developing countries, monitoring data are often collected from more commercially-oriented, large scale farms, that may not be fully representative of ordinary farms.
Feed and nutrition standards	Feed and nutrition standards contain the nutrition requirements of different types of animal. Similar to the IPCC equations, nutrition requirements are based on energy intake requirements, and thus must consider milk yield alongside other metabolic functions. Where farmers refer to nutrition standards to guide their management practices, these standards can be assumed to be applicable to describing actual farming practices.
Expert judgement	Veterinary agencies calculate immunisation doses in ml per kg body weight, and may be able to provide estimates of live weight for different livestock sub-categories. Livestock scientists or industry experts may also be able to provide estimates based on expert judgement.
National accounts	National accounts use technical coefficients to estimate annual milk yield per milking animal in order to assess the contribution of livestock to the national economy.
FAOSTAT	FAOSTAT provides estimates of total national milk output for several types of ruminant, as well as estimates of yield per head. Note: check the FAOSTAT definitions and standards to understand which components of milk production are included in FAO estimates.

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Tool B.10: Potential data sources for milk fat and protein content

Official statistics	Some countries regularly report milk fat content on the basis of milk quality monitoring programmes.
Statistical databases	Databases on milk fat and protein content are often kept by national livestock recording programmes, breed associations or industry organisations. However, care should be taken to assess whether these databases are representative of the production systems in the inventory. For example, in many developing countries, monitoring data are often collected from more commercially-oriented, large scale farms, that may not be fully representative of small-scale farms.
Industry organisations	Industry associations, breed associations and milk processors may collect data on milk fat and protein contents, since these parameters are closely related to the economic value of processed milk products.
Research studies	Sample surveys conducted by researchers may be reported in scientific publications.

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Tool B.11: Potential data sources for wool production

Official statistics	Some countries regularly report wool production through annual administrative statistics.
Statistical databases	Databases on wool production may kept by national livestock recording programmes, breed associations or industry organisations. However, care should be taken to assess whether these databases are representative of the production systems in the inventory. For example, in many developing countries, monitoring data are often collected from more commercially-oriented, large scale farms, that may not be fully representative of small-scale farms.
Industry organisations	Industry associations and breed associations may collect data on wool production for use in estimating prices and trading volumes.
Research studies	Sample surveys conducted by researchers may be reported in scientific publications.
FAOSTAT	FAOSTAT provides estimates of total national wool output as well as estimates of wool production per head.
Expert judgement	Livestock experts, breeders and wool producers should be able to estimate wool production.

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Tool B.12: Potential data sources for diet composition

Official statistics	Some countries regularly report output of the main fodder and feed crops, which can be used together with livestock population and estimates of nutrition requirements to estimate diet composition
Feed and nutrition standards	Feed and nutrition standards contain the nutrition requirements of different types of animal, and may include feed tables based on animal nutrition requirements. Where farmers refer to nutrition standards or feed tables to guide their management practices, these standards can be assumed to be applicable to describing actual farming practices.
Industry organisations	Industry associations may collect data on feed composition, for example for purposes of monitoring costs of production in more intensive systems
Research studies and reports	Small-scale sample surveys conducted by researchers may be reported in scientific publications, which may include information on either feed availability or feeding practices as-fed to different animal sub-categories. Forage production and promotion programmes implemented by national or international organisations and NGOs may have conducted surveys on feed availability and feeding practices. Larger-scale feed assessments have been conducted in a few countries, with results available in national assessment reports. International assessments of feed composition are also available for some livestock types.
Expert judgement	Livestock producers, industry experts, extension workers and livestock scientists should be able to estimate diet composition and feeding practices specific to each animal sub-category.

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Tool B.13: Potential data sources for feed digestibility and crude protein

Feed and nutrition standards	Feed and nutrition standards contain the nutrition requirements of different types of animal, and the nutrition composition of fodder and feedstuffs.
Industry organisations	Industry associations may have data on nutrient composition of fodder and feed stuffs produced or used by their members
Research studies and reports	Nutrient content of fodder and feedstuffs – often focusing on one fodder type or multiple types in targeted regions – may be reported in scientific publications. Reports collating results from multiple studies may also be available. There may also be publications by UN FAO and other international organisations.
Databases	International databases of feed nutrient composition, e.g. www.feedipedia.org, and other databases listed at https://www.feedipedia.org/content/feed-databases Regional research organisations may also maintain databases, e.g. https://feedsdatabase.ilri.org for Sub-Saharan Africa
Expert judgement	Livestock and fodder scientists or industry experts may have access to information on feed nutrient composition and be able to provide estimates based on expert judgement.

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Tool B.14: Potential data sources for the percentage of females giving birth

Official statistics	Some countries regularly collect and report data on the proportion of breeding females giving birth.
Sample surveys	Sample survey results may be available in scientific publications or grey literature published by research organisations, industry organisations, donor projects or NGOs.
Industry organisations	Databases on female reproduction are often kept by national livestock recording programmes, breed associations or industry organisations. However, care should be taken to assess whether these databases are representative of the production systems in the inventory. For example, in many developing countries, monitoring data are often collected from more commercially-oriented, large scale farms, that may not be fully representative of ordinary farms.
Research studies and reports	Sample surveys conducted by research institutes or livestock development programmes may have collected data on calving or lambing rates or proxy variables such as calving intervals, particularly because indicators of reproductive performance are key indicators for livestock production.
Expert judgement	Livestock scientists or industry experts may be able to estimate the proportion of females giving birth.

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Tool B.15: Potential data sources for the proportion of manure managed in different manure management systems

Sample surveys	Sample survey results may be available in scientific publications or grey literature published by research organisations, industry organisations, donor projects or NGOs. Note that some relevant sample surveys may have been conducted with a focus on rural energy or environmental pollution rather than livestock production. National biogas promotion programmes may have conducted large-scale sample surveys.
Industry organisations	Particularly where manure management is an environmental issue, industry organisations may have data on manure management practices by their members
Research studies and reports	Sample surveys conducted by research institutes or livestock development programmes may have collected data on manure management systems. However, attention should be paid to whether the manure management systems defined in research studies are aligned with the IPCC definitions
Carbon market project documents	Carbon market projects that produce biogas from manure should all have undertaken a baseline survey. Databases of carbon market projects can be found at https://cdm.unfccc.int/Projects/registered.html and https://mer.markit.com/br-reg/public/index.jsp?entity=project&sort=project_name&dir=ASC&start=0&entity_domain=Markit,GoldStandard
Expert judgement	Livestock and industry experts may be able to estimate the proportion of manure managed in different manure management systems.

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Tool B.16: Template for data quality assessment spreadsheet

In Section **B.1.1 General guidance**, Step 4 gives guidance on assessing the quality of identified data sources. This assessment can help inventory compilers decide whether to use data from a given source, and to be aware of data quality issues that may affect the quality of the overall inventory. Tool B.16 provides a template for recording potential data sources and assessing their quality against the following criteria:

- **Transparency:** Are data sources and methods transparently described?
- **Comparability:** Are the definitions and units in the data source in line with the inventory and IPCC requirements?
- **Completeness:** Does the data source cover all items contained in the indicator?
- **Consistency:** Are data definitions, collection and analysis methods consistent with those used in other data sources for the same time series in the inventory?
- **Accuracy (sampling):** Was a representative sampling method applied?
- **Accuracy (non-sampling):** Were appropriate data collection and analysis methods applied?
- **Accessibility:** How easy is it to obtain the data in the data source?
- **Timeliness:** Is the data accessible on a time frame suitable for regular inventory compilation?

Each data source is scored against each criterion on a scale of 1-4, with 4 indicating ‘no data quality issues’ and 1 indicating ‘major issues’. The indicators and scoring criteria are described in the ‘Indicators and scoring’ worksheet in the spreadsheet file. The spreadsheet file contains worksheets for each of the parameters required to estimate Tier 2 livestock GHG emissions, and a summary spreadsheet that visually shows which parameters score higher or lower on each of the quality criteria. The template contains some illustrative contents that should be replaced by country-specific data when used.

The tool can be downloaded from this external link: https://www.agmrv.org/knowledge-portal/resources/template-spreadsheet-for-assessing-the-quality-of-tier-2-livestock-activity-data/

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B.4 Methodological guidance

This section explains methodological issues that affect how inventory compilation decisions may be made. The focus topics are:

Methodological Focus B.1: The difference between parameters, indicators and activity data

The parameters in the IPCC equations are different from the activity data itself. Appreciating this difference is useful. Some parameters can be estimated directly using livestock activity data, but others require analysis of available datasets to estimate the required parameter. Data are pieces of information that are directly observed or collected in the field. For example, a data is the weight of one goat as measured with a scale or a tape, or the answer by a farmer to the question: 'How many kilos of compound feed did you purchase last week?' Indicators are 'statistical variables that help to transform data into relevant information' (UNECE, 2007). Simple indicators are aggregations of data standardized by some time, space and/or other dimension (e.g. value). Examples of indicators are the "average number of adult animals in a given country / year" or "the average live weight of a cow". More complex indicators are produced by combining a variety of data, such as the "annual average milk yield" and the "weight gain between birth and weaning". The former would require information on the length of the lactation period per cow per year and the average milk yield per day over that period. The latter would require information on the weight at birth as well as at weaning of the animal. This implies that the parameters required in the IPCC equations can either be directly estimated using indicators derived from activity data (e.g. average live weight) or by combining indicators to estimate the parameter (e.g. population X proportion of cows in the herd = population of cows in the herd).

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Methodological Focus B.2: Summary statistics and confidence intervals

Common statistical measures to describe a distribution include the mean, median, standard deviation and standard error.

The **mean** of a sample is often taken as the best estimate of the true average value of a variable in the population. The mean value of a sample is simply the average value, calculated by summing all individual values and dividing by the total number of values:

$$\text{Mean} = \frac{\sum x_i}{N}$$

The **median** is the middle value in a dataset that has been arranged in order of magnitude.

The **mode** is the most commonly occurring value in a dataset.

The **standard deviation** (s.d., or σ) is a measure of the spread of values in a dataset, and indicates how much the values differ from the mean value in the dataset. The standard deviation for a sample is calculated as:

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

where N is the number of observations in the sample; $\{\chi_1, \chi_2, ..., \chi_n\}$ are the observed sample values, and $\bar{\chi}$ is the mean value of the sample observations.

The **standard error** (s.e., or $\sigma_{\bar{\chi}}$) is calculated as the standard deviation (σ) divided by the square root of the sample size (n):

$$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$$

The standard deviation is used to indicate the spread of the data from the mean, while the standard error is used to indicate the precision of the mean estimate or to test for differences between means. The sample mean plus or minus the standard error multiplied by 1.96 gives the upper and lower bounds of the 95% confidence interval.

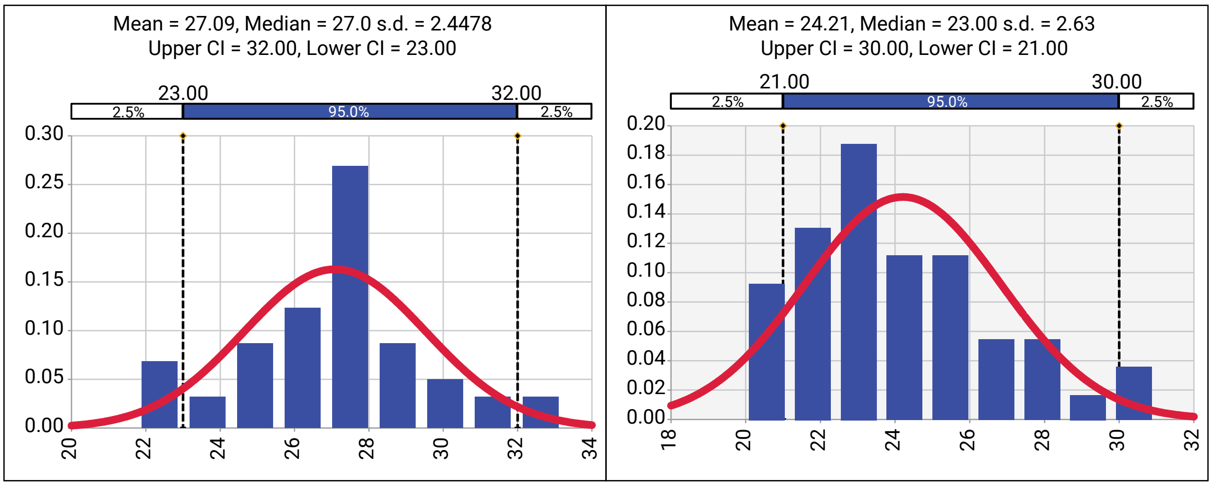
Central limit theorem states that as sample size increases, the distribution of values around the mean will increasingly approximate a normal distribution (Figure 12**(a)**). When variables are normally distributed, the sample mean will approximate the population mean. However, some variables may not be normally distributed (e.g. Figure 12**(b)**). When variables are not normally distributed, the mean is not always the best measure of central tendency. In the example in Figure 12**(b)**, the median value is a better measure of central tendency than the mean. When raw data are available, it is common to transform the data so that it approximates a normal distribution. Depending on how the data is skewed, it may be possible to transformed the data to normality using Tukey's 'ladder of transformations':

$$\frac{-1}{x} \qquad \log(x) \qquad \sqrt{x} \qquad x^2 \qquad x^3 \qquad antilog(x)$$

← correct right skew (e.g. when mean > median) → correct left skew (e.g. when mean < median)

Figure 12: Normal and non-normal distributions

(a) Normally distributed data, showing upper and lower confidence intervals (b) Non-normal data



Therefore, when using raw data or inspecting survey results reported in literature, it is important to understand the distribution of the data and to assess which measure of central tendency is most appropriate to use in the inventory.

IPCC guidelines on uncertainty analysis states that emissions in each category should be reported with a 95% confidence interval. The 95% confidence interval is the range that has a 95% probability of containing the true value of the emissions. The upper and lower bounds of a 95% confidence interval are shown in **Figure 12 (a) and (b)**. For uncertainty analysis using the Monte Carlo approach (see **D.1.4 Uncertainty analysis**), depending on the data input requirements of the specific software used, it is necessary to know the shape of the distribution, the mean value and the standard deviation.

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Methodological Focus B.3: When do I need to estimate the number of days alive for a livestock sub-category?

For livestock sub-categories that are typically alive for more than one year (e.g. productive cattle, breeding stock), it is generally sufficient to obtain annual average population estimates from annual inventory data (IPCC 2006 Vol. 4 Ch. 10 page 10.8). In countries where population estimates are made at one time each year, this annual estimate can be used.

If estimates are made at two points in the year (e.g. end of June and end of December), the average of these two values or a rolling average of three livestock inventory estimates can be used (see **Worked example B.1: Estimating average annual population in Hungary's inventory**). If only one of these values is used, the time series may be consistent, but the estimate may be biased upwards or downwards by not accounting for seasonal changes in the population due to births or off-take.

Some livestock sub-categories are typically not alive for a complete calendar year. For example, one fattening cycle in a feedlot may last only 4-6 months, or lambs may be born in spring (or autumn) and sold before winter (or summer). In this case, to estimate the annual average population alive it is necessary to also have an estimate of the number of days alive for each relevant sub-category. To estimate annual average population alive, the 2006 IPCC Guidelines gives the following equation:

$$AAP = Days\_alive \times \left(\frac{NAPA}{365}\right) \qquad \text{(IPCC 2006, Equation 10.1)}$$

where *AAP* is annual average population, and *NAPA* is the number of animals produced annually. For potential data sources on number of days alive, see **Tool B.4**. For a worked example, see **Worked example B.2: Applying the IPCC equation for annual average population**.

Where cattle or sheep breed in an annual cycle, but some sub-categories (e.g. lambs, calves grown for slaughter) are not alive for the whole calendar year, some countries calculate the emission factor on an annual basis and apply a discount reflecting the proportion of the year that the animal is alive:

$$\textit{Annual emissions} = AP_i \times EF_{final}$$

where
AP_i is the annual population of sub-category ***i***, head; and

$$EF_{final} = EF_{annual} \times \left(\frac{Days\_alive}{365}\right)$$

This is mathematically equivalent to calculating annual average population using the IPCC method. For a **Worked example B.3: Adjusting the emission factor to account for days alive**.

In countries undergoing rapid commercialization of livestock production, change in the parameter *Days_alive* can be a key driver of reduced GHG emission intensity from livestock production if increasing off-take rates are associated with shorter average life spans for animals (see Yu et al. 2018).

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Methodological Focus B.4: Should I estimate weight gain for adult animals?

Mature weight is the weight of an animal when skeletal development is complete. For cattle, one 'rule of thumb' suggests that maturity may be reached after four years of age, but the specific age may differ by breed and production conditions. Mature weight should be estimated as 'shrunken body weight' (i.e. body weight after fasting) which can be calculated as live weight * 0.96. Mature weight varies between small and large breeds. For cattle, IPCC (2006, page 10.12) suggests that adult animals may be assumed not to grow, so weight gain can be assumed to equal zero. In reality, the average age of cattle in the herd may be less than four years of age, so cattle may continue to grow between their average age and the age at maturity. The IPCC suggests that the growth rate will be small and can be ignored. An example illustrating this is given in **Worked Example B.4: Whether to estimate weight gain for dairy cows**.

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Methodological Focus B.5: Should I account for weight gain and weight loss in different seasons?

It is common for cattle and sheep to gain weight during one part of the year and lose weight in another season when feed resources are limited. In addition to seasonal factors, cows and ewes also typically lose weight after calving / lambing because of a negative nutritional balance in late pregnancy and early lactation. The IPCC Good Practice Guidance (IPCC 2000, Ch.4) included equations to account for seasonal weight loss and weight gain for cattle, but not for sheep. However, these were dropped in IPCC (2006) where it states: "Reduced intakes and emissions associated with weight loss are largely balanced by increased intakes and emissions during the periods of gain in body weight." Thus, the IPCC equations can be implemented by using the annual average live weight. If, for other reasons, it is decided to estimate emissions for each season, this can be done applying the IPCC equations, but adjusting Equation 10.21 for the number of days in each season. Very few countries have used seasonal emission factors in their inventories, and if they do it is most often so that the methane conversion factors can vary to reflect seasonal differences in diet, rather than seasonal differences in live weight (see, e.g. Denmark's livestock inventory).

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Methodological Focus B.6: Using slaughter weight to estimate live weight

IPCC (2006) states that: "slaughter-weight data should not be used in place of live-weight data as it fails to account for the complete weight of the animal. Additionally, it should be noted that the relationship between live-weight and slaughter-weight varies with breed and body condition." Furthermore, the average weight of animals sent to slaughter may not be representative of the average weight of animals kept in the herd.

Slaughter weight (SW) can be converted to live weight (LW) by dividing by the dressing percentage (DP):

$$LW = \frac{SW}{DP}$$

Slaughter weight data may be available from slaughter houses. Dressing percentage may be available from research studies or from industry sources. It should be taken into account that dressing percentage may vary by breed and body condition. Examples of how countries have made use of slaughter weight in estimating live weight in their GHG inventories are provided in case studies on the https://www.agmrv.org/knowledge-portal/case-studies/inventory-practice-estimating-cattle-weights-in-the-uk/ and the https://www.agmrv.org/knowledge-portal/case-studies/inventory-practice-improving-estimates-of-cattle-weights-in-new-zealand/.

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Methodological Focus B.7: Using animal recording databases

Animal recording databases contain detailed data collected using consistent methods over time on animal characteristics (e.g. breed) and performance (e.g. reproduction, milk yield, live weight etc). They are often maintained by either public livestock recording bodies or breed associations. Two examples illustrate their potential use as well as the risks of relying on this data source.

For non-dairy cattle, Portugal's GHG inventory uses animal performance data estimated from animals recorded by 17 breeders' associations. The data recorded includes the number of animals, reproductive parameters such as weaning age, and data on weight at birth, at 7 months and at adult age. The registries contain data on about 20% of the national breeding herd, but because most of the remaining animals in the country derived from these registered breeding animals, it was assumed that they would have similar characteristics to those in the database. The underlying assumption would be that breeds and management on farms and in the registered herd are similar.

Kenya's publicly-run Livestock Recording Centre keeps a database on the live weights of beef cattle at different ages. The beef cattle database uses data collected only from commercial farms, which represents a very small proportion of the total national beef cattle herd. More than 80% of beef cattle are raised in pastoral systems, which use different breeds, feeding and management practices from the commercial farms. It is likely that the beef cattle in this database produce higher emissions than those on pastoral farms, due to their large size, higher growth rates and higher milk yields. Therefore, relying on this database to characterise beef cattle would result in an over estimation of emission for the beef herd in Kenya.

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Methodological Focus B.8: Technical coefficients in national accounts

National accounts bring together units and transactions to estimate the level of production, income, consumption, trade and wealth in a country. It includes a module on livestock that measures the contribution of the different livestock sub-sectors to the national economy. A common method for doing this is to assign fixed technical coefficients (or "technical conversion factors") to livestock population or off-take numbers, which converts numbers of animals into output per head.

For example, In Kenya, total milk output is estimated as:

total milk output = dairy cattle population X proportion of cows in the herd X proportion of milking cows X annual milk yield per head.

The standard coefficients are:

*Adult cows are **55%** of the total dairy herd*

*Lactating cows are **45%** of the adult cow herd*

Annual milk yield per lactating cow is 1800 litres.

Similar coefficients are used to estimate the carcass weight of cattle and sheep sold. If there is no other country-specific data, it could be possible to use the coefficients in national accounts. However, guidelines produced by the Global Strategy on Agricultural and Rural Statistics notes that the coefficients used by national statistical offices are rarely based on a nationally representative sample (being mostly based on expert opinion or 'grey literature'), and are infrequently updated.

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Methodological Focus B.9: Estimating feed composition using feed availability or data on feed as-fed

In some production systems, where cultivated fodder crops and other supplements are limited, estimates of the availability of different types of feed may be sufficient to represent the diet composition of different animal sub-categories. In more intensive or commercially oriented production systems, however, livestock keepers often feed different feedstuffs to different sub-categories of animal. For example, lactating cows or animals grown for fattening may be fed particular diets. Because these diets are intended to increase milk yield or growth, they often include diet components that with a higher feed digestibility and higher protein content than other available feeds. These diet components may therefore have a strong impact on the average digestibility of feed for these sub-categories.

Table 13 shows the findings of a survey of 262 dairy farming households in central Kenya who stall-raise their cattle. The figures shown are based on farmer-reported estimates of amounts fed in the wet and dry seasons. The digestibility of each feedstuff was estimated using literature values. Of all the feedstuffs reported, about 30% were reported to be fed to specific cattle sub-categories, rather than being fed to all animal types on the farm. Napier grass, other cultivated grasses (e.g. Rhodes grass) and maize together make up more than 60% of reported feedstuffs fed. However, while these three fodder categories account for only 60% of cow diet, they account for almost 70% of the diet of adult males and calves. Concentrate is a far greater proportion of the diet for cows than for other sub-categories. If feed digestibility had been estimated on the basis of total available feed, the digestibility of feed in cow diets would be underestimated by about 0.5%, which (assuming all other variables are unchanged) would have increased the emission factor for stall-raised cows in Kenya's inventory by 1.25%. For growing males, the emission factor would have been underestimated by 2.19%

Table 13: Diet composition and average digestibility for stall-raised dairy cattle in central Kenya

Type	Napier	Other grass	Maize	Protein fodder	Concentrate	Maize germ	Minerals	Other	Average DE%
All	23.9%	8.6%	31.3%	1.2%	9.4%	3.9%	4.8%	17.0%	60.04
Cow	22.6%	8.6%	29.3%	0.9%	13.5%	4.7%	4.4%	15.6%	60.53
Heifer	22.3%	8.8%	35.0%	1.2%	6.7%	3.5%	6.2%	16.3%	59.72
Adult male	28.8%	4.5%	34.7%	2.6%	4.6%	4.7%	2.9%	17.2%	58.24
Growing male	19.6%	9.9%	34.5%	1.1%	2.6%	2.8%	8.6%	20.9%	59.20
Calves	28.6%	8.7%	31.8%	1.5%	3.3%	2.1%	4.3%	19.8%	59.51

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Methodological Focus B.10: Predicting feed digestibility from other chemical characteristics of feed

The IPCC equations require an estimate of digestible energy as a percent of gross energy (DE%). Scientific publications on feed nutrient contents often do not report their results using this measure of feed digestibility. Where feed digestibility is not reported in DE%, IPCC (2006) recommends to predict DE% from other chemical characteristics, such as Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF) or crude protein, and refers to the Nutrient Requirements of Dairy Cattle published by NRC in 2001 for guidance on prediction of DE from these other chemical characteristics.

NRC (2001: 16) provides the following equations:

For most feeds:
DE (Mcal/kg) = (tdNFC/100) X 4.2 + (tdNDF/100) X 4.2 + (tdCP/100) X 5.6 + (FA/100) X 9.4 - 0.3

For animal protein meals:
DE (Mcal/kg) = (tdNFC/100) X 4.2 + (tdCP/100) X 5.6 + (FA/100) X 9.4 - 0.3

where Mcal/kg can be converted to MJ/kg by multiplying by 4.184; tdNFC = truly digestible nonfiber carbohydrate; tdNDF = truly digestible Neutral Detergent Fiber; tdCP = truly digestible crude protein, and FA is fatty acid content. Further details are given in NRC (2001).

Another commonly reported measure of feed digestibility is dry matter digestibility (DMD). Following Nutrient Requirements of Domesticated Ruminants, published by CSIRO in 2007:

1) $$M/D = 0.172 \times DMD - 1.707$$

2) $$DE = \frac{ME}{0.81}$$

3) $$GE = 18.4MJ$$

where the value for GE is a default value that can be replaced by feed-specific values; M/D = Megajoules (MJ) of metabolizable energy per kg of dry matter feed; ME = metabolizable energy (MJ); DE = digestible energy (MJ) and GE = gross energy (MJ). Thus, for example, if a feedstuff has DMD of 60%, then

1) $$M/D = 0.172 \times 60 - 1.707 = 8.613MJ$$

2) $$DE = \frac{8.613}{0.81} = 10.63MJ$$, and

3) $$DE\% = \frac{10.63}{18.41} \times 100 = 57.78\%$$
.

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Methodological Focus B.11: Calculating an appropriate value for the coefficient for activity.

The 2006 IPCC Guidelines Table 10.5 gives default values for activity coefficients. For example, for cattle, the values are 0 for stall raised animals, 0.17 for cattle grazing confined pastures, and 0.36 for cattle grazing extensive rangelands. However, there is a wide variety of grazing systems, and sometimes it is not immediately obvious whether to apply the activity coefficient for confined pastures or for extensive rangelands.

The IPCC equations for estimating net energy for activity are based on the approach set out in the Nutrient Requirements of Dairy Cattle published by NRC in 2001. NRC (2001) estimates energy expenditure for activity as deriving from two components:

1) Energy for locomotion (Mcal) = 0.00045 x LW x km

where 0.00045 is Mcal/kg live weight, LW is live weight and km is kilometres travelled; and

2) Energy for eating (Mcal) = 0.0012 x LW

where 0.0012 is Mcal/kg live weight. So:

3) *Energy for activity = (0.00045 x LW x km) + (0.0012 x LW)*

Mcal is then converted to MJ by multiplying by 4.1868.

The coefficient for activity (C_a) is expressed as a proportion of net energy for maintenance ($NE_m = Cf_i * LW^{0.75}$), so net energy for activity is divided by NE_m. Thus:

$$Ca = \left(\frac{((0.00045 * LW * km) + (0.0012 * LW) * 4.1868)}{(Cfi * LW^{0.75})}\right)$$

For example, this would imply that for a 365 kg cow, a C_a value of 0.17 corresponds to a daily average grazing distance of 5.3 km, while a value of 0.36 corresponds to a distance of 14.2 km.

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B.5 Worked examples

This section provides worked examples to show how the methods referred to in the Practical Guidance section can be implemented. The worked examples given include:

Worked example B.1: Estimating average annual population in Hungary's inventory

Since 2009, the Hungarian Central Statistics Office has conducted two censuses of animal numbers each year. One survey is conducted in June and one in December. The annual average population for a year t is calculated as follows:

$$N_t = \frac{(0.5 \times N_{Dec,t-1}) + (N_{June,t}) + (0.5 \times N_{Dec,t})}{2}$$

where:
N_t = rolling average annual population in a year t
$N_{Dec,t-1}$ = population in December of the year t-1
$N_{Jun,t}$ = population of a livestock category in June of the year t
$N_{Dec,t}$ = population in December of the year t.

Half of the population count from the previous December is included to represent population during the months before June of year t. The effect of using this method is to smooth out the seasonal changes in population.

Source: Hungary NIR 2018

Worked example B.2: Applying the IPCC equation for annual average population

The 2006 IPCC Guidelines (Vol. 4 Ch.10) gives the following equation for the annual average population of animal categories that live for less than a year:

$$AAP = Days\_alive \times \left(\frac{NAPA}{365}\right)$$

Where:
AAP is the annual average population

$NAPA$ is the number of animals produced annually.

Imagine that Country X has a large output of lamb that are sold at a national festival in August of each year. Survey data show that lambs are mainly born in the dry season, from September to November, and that 30% of lambs are slaughtered each year in August. The annual December census in 2017 counted a total population of 1,000,000 lambs. Of these, 300,000 lambs lived for only 10 months (i.e. 300 days from October to end of July), while 700,000 lambs lived for the full year. The average annual population of lambs for 2018 can therefore be estimated as:

$$AAP = \left(300 \times \frac{300{,}000}{365}\right) + \left(365 \times \frac{700{,}000}{365}\right) = 946{,}575\ head$$

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Worked example B.3: Adjusting the emission factor to account for days alive

For animal sub-categories that are only alive for part of the year, several countries calculate an annual emission factor and then multiply it by the proportion of the year alive:

$$EF_{final} = EF_{annual} \times \left(\frac{Days\_alive}{365}\right)$$

For example, Hungary's GHG inventory distinguishes 8 sub-categories of non-dairy cattle, including 2 categories for non-dairy cattle < 1 year old, "bovines for slaughter and other calves", which are divided into male and female sub-categories. The national inventory report transparently presents the key input data used to estimate enteric fermentation emissions for both sub-categories, and estimates gross energy of 94 MJ day^{-1} for both males and females. For males, a methane conversion factor of 5.53 is used, considering 60 days of consuming only milk and the proportion of concentrate in the diet (i.e. 30%). On an annualized basis, this would equate to an emission factor of 34.1 kgCH_4 head^{-1} year^{-1}. However, considering the timing of births and slaughter in the year, animals in these sub-categories are only alive for about 8.5 months (i.e. 255 days) of the year. So:

$$EF_{final} = 34.1 \times \left(\frac{255}{365}\right) = 23.8\ kgCH_4 head^{-1} year^{-1}$$

The inventory reports a value of 24 $kgCH_4$ head-1 year-1, and the difference with the estimated emission factor represents the effect of rounding.

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Worked Example B.4: Whether to estimate weight gain for dairy cows

Dairy cows in the intensive production system in Kenya are mostly Holstein-Friesian and their crosses with indigenous Zebu cattle. A survey took heart girth measurements from 275 cows, which were converted to estimates of live weight (kg). The average liveweight of all cows measured was 365.35 kg, and their average age was 4.72 years. The average live weight of cows of 4th parity and above was 373.35 kg and their average age was 5.88 years, i.e. about 422 days older than the average cow. The difference in weight (i.e. 373.35 – 365.35 kg) divided by 422 days gives an estimated average daily weight gain for mature cows of 0.019 kg, or just 19 grams. Multiplying live weight by 0.96 to estimate shrunken body weight gives a mature weight of 358.4 kg, which is less than the average live weight for the cow category. Since negative growth does not make sense, an alternative is to assume that average daily weight gain is zero.

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Worked Example B.5: Estimating the proportion of cows giving birth from calving interval data

Data is often collected in sample surveys on calving interval. From a production perspective, this is an indicator of animal and herd efficiency. Calving interval is the number of days for an individual cow between one calving and the next calving. It can be used to give a rough estimate of the calving rate as follows:

$$Calving\ rate\ (\%) = \left(\frac{365}{calving\ interval\ in\ days}\right) \times 100$$

For example, a literature review for Kenya's dairy GHG inventory identified few direct reports of calving rates, but many reports of calving intervals. In the intensive production system, the mean calving interval was 590 days and the calving rate was estimated as (365/590) X 100 = 61.86%. In the semi-intensive system, the mean calving interval reported was 566 days, so the calving rate was estimated as (365/566] X 100 = 64.49%.

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Worked Example B.6: Calculating a weighted average activity coefficient

The IPCC equations for enteric fermentation give default values for the coefficient for activity (i.e. stall-fed = 0, grazing confined pasture = 0.17). If feeding systems vary by season, a time-weighted average value for Ca can be calculated:

$$C_a = \left[(days_{S1}/365) \times C_{a,S1}\right] + \left[(days_{S2}/365) \times C_{a,S2}\right]$$

where $days_{Si}$ is the number of days in the year animals spend in feeding system i, and $C_{a,Si}$ is the average coefficient for activity in feeding system i. For example, Belgium's GHG inventory cites activity data suggesting that in 2017 dairy cows spent 51 days of the year grazing on confined pastures and the remaining 314 days in stalls. Hence:

$$C_a = [(314/365) \times 0] + [51/365) \times 0.17] = 0.0238$$

Activity data were available at irregular intervals, so the inventory adopted a fixed value for C_a in different periods, as shown in **Table 14**.

Table 14: Activity coefficient for cattle in different periods used in Belgium's GHG inventory

	2000-2005	2006-2010	2011-2014	2015-2017
Bovine < 1 year	0.0068	0.0051	0.0051	0.0051
Bovine 1-2 years	0.0068	0.0034	0.0034	0.0051
Dairy cows	0.0340	0.0272	0.0238	0.0238

Source: Belgium 2019 National Inventory Report

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Worked Example B.7: Aligning livestock sub-category definitions for a consistent time series

Guidelines for the World Census of Agriculture 2020 suggests to group animals by age, sex and purpose. Countries are free to choose the specific categorizations used. In some countries, categorizations have changed over time, which presents a challenge for producing a consistent livestock population time series. **Table 15** gives an example of how Croatia addressed the challenge of changing categories for non-dairy cattle. Categories used by the national statistics agency in different periods were mapped onto broad sub-categories consistent with the terminology used in the IPCC Guidelines. Thus, although the specific sub-categories of 'young cattle' defined in national statistics have changed over time, in all periods 'young cattle' includes all cattle sub-categories less than 2 years old. Similarly, 'adult non-dairy cattle' includes all sub-categories above 2 years old.

Table 15: Categorization of non-dairy cattle in different periods used in Croatia's GHG inventory

	Central Bureau of Statistics categories		
IPCC category	1990-1999	2000-2006	2007-2017
Adult non-dairy cattle	• Heifers • Other cows • Other (bull, ox)	• Other cows • Other (bull, ox) • Pregnant heifers • Calves > 2 years	• Heifers > 2 years • Cows (females that have calved) • Other bovines > 2 years
Young cattle	• Bovine animals aged <2 years	• Calves <3 months • Calves 3 month – 1 year • Calves 1-2 years	• Bovine animals <1 year • Bovine animals 1-2 years

Source: Croatia 2019 National Inventory Report, page 194.

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Worked Example B.8: Estimating calf milk consumption using the NRC method

Nutrient Requirements of Dairy Cattle (NRC, 2001, page 214) presents a method for estimating the dry matter intake of calves fed on milk. The first step is to calculate the metabolizable energy (ME, Mcal) required for maintenance and growth:

$$ME = 0.1LW^{0.75} + (0.84LW^{0.355} \times LWG^{1.2})$$

where LW is live weight (kg), and LWG is daily live weight gain (kg day^{-1}). Assuming whole milk has an ME content of 5.37 Mcal per kg dry matter (DM), and the DM content of milk is 12.5%, then daily milk consumption by a calf feeding only on milk (Milk$_{calf}$, kg day^{-1}) can be calculated as:

$$Milk_{calf} = \left(\frac{ME}{5.37}\right) \div 12.5\%$$

For example, for a calf weighing 30 kg, with daily weight gain of 0.3 kg, daily fresh milk consumption is predicted as:

$$\left[\frac{[0.1 \times (30^{0.75})] + [0.84 \times (30^{0.355}) \times (0.3^{1.2})]}{5.37}\right] \div 12.5\% = 2.90\ kg\ milk$$

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B.6 Additional resources

IPCC Guidance

IPCC (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

IPCC (2006) Vol. 1 Ch. 1 Introduction

IPCC (2006) Vol. 1 Ch. 2 Approaches to Data Collection

IPCC (2006) Vol. 4 Ch. 10 Emissions from Livestock and Manure Management.

IPCC (2019) 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

CGE Training materials for the preparation of national communications from non-Annex 1 Parties contains training modules on approaches to data collection

On available data sources and statistics:

General guidance on available data sources and statistics relevant to agriculture is given in:

UNECE (2007) Rural Households' Livelihoods and Well-being: Statistics on rural development and household income

Specific guidance on available data sources and statistics for livestock can be found in:
GSARS (2018) Guidelines on Methods for Estimating Livestock Production and Productivity

On data quality:

International guidance on the quality of statistics, including agricultural statistics, includes:

United Nations (2014) United Nations Fundamental Principles of Official Statistics

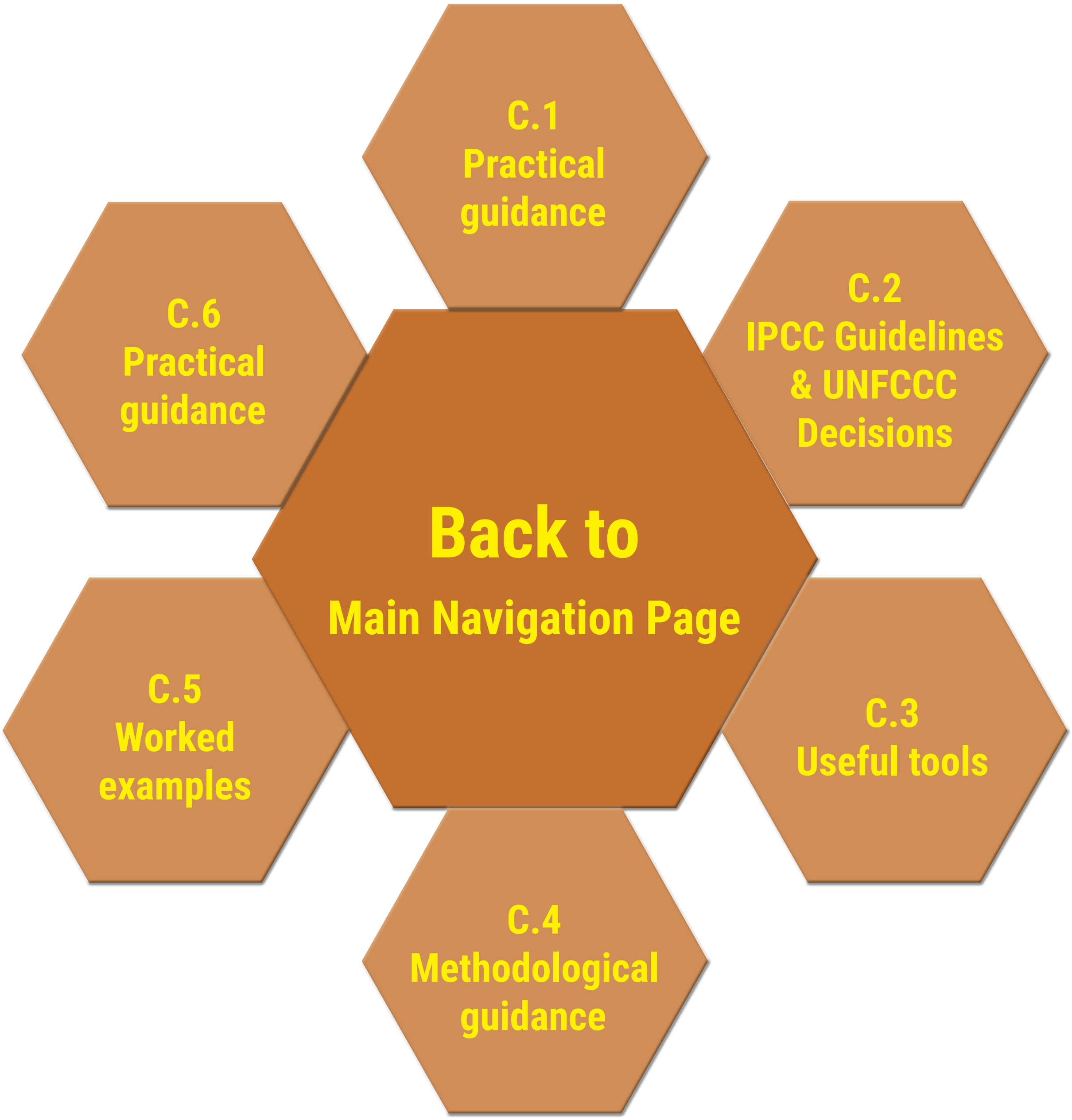
Many countries' statistical authorities have also established national quality assurance frameworks, following guidelines from the United Nations: UN National Quality Assurance Framework

For international agricultural statistics, FAO has set the FAO Statistics Quality Assurance Framework FAO data can be accessed at http://www.fao.org/faostat/en/. The IPCC and FAO have also produced a report on how to use FAO data for national GHG inventory purposes.

Examples of methods used in livestock GHG inventories:

Examples of how other countries have collected and processed data on livestock can be directly viewed in the national inventory report submissions by developed countries, and in national inventory reports submitted together with national communications or biennial update reports by developing countries. Selected case studies of methods used to compile Tier 2 livestock GHG inventories can be found at https://www.agmrv.org/knowledge-portal/case-studies/.

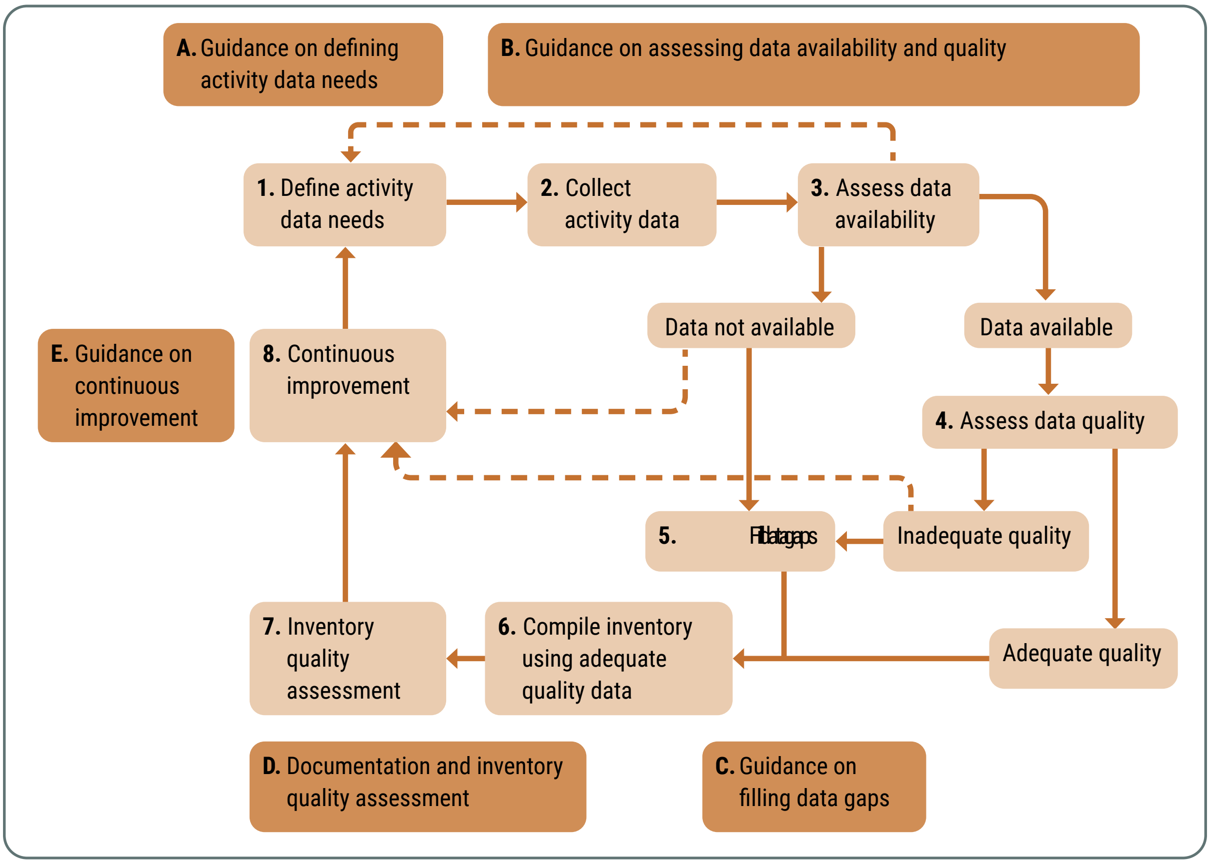
C. Guidance on filling data gaps



C.1 Practical guidance

In **Figure 13**, activity data gaps may either exist due to lack of information (i.e. no data at all) or due to a data quality gap (i.e. there is some data but it is not sufficient quality to use). Section **C.1.1 Filling data gaps using available data** gives general guidance on how to use available data to fill data gaps, and **C.1.2 Collecting new data to fill data gaps** gives general guidance on methods for collecting new data to fill data gaps. The focus in **C.1.2 Collecting new data to fill data gaps** is on methods that can provide data to meet the immediate needs of inventory compilation. Longer-term data collection and inventory improvement activities, including improvements in national livestock statistical systems, are addressed in Section **E. Continuous improvement**.

Figure 13: Activity data compilation framework



C.1.1 Filling data gaps using available data

The IPCC guidelines present various methods for filling data gaps. The specific method used will depend on the type of data gap. No matter what method or data is used, it is important that data sources and methods are justified and well documented, as described in Section **D.1.1 Documentation**.

IPCC guidelines and UNFCCC decisions require that inventories provide a consistent time series (see **IPCC Guidelines and UNFCCC decisions on time series consistency**). If a time series for a parameter has been estimated but there are gaps for data in some years, methods for filling time series gaps can be used. These methods are described in IPCC 2006 Guidelines Vol. 1 Ch. 5. These methods are also recognized in the Modalities, Procedures and Guidelines on transparency in the Paris Agreement (Annex, paragraph 27) (see **IPCC guidelines on gap filling methods**). Time series gap filling methods include:

- **Interpolation:** If there is a gap of one or more years in a time series with known earlier and later values, and a trend is clearly present, the missing years can be filled using linear or non-linear interpolation.
- **Extrapolation:** If there is a gap of one or more years at the beginning or end of a time series, and a clear trend is present in the existing data, the missing years can be filled by extrapolating the existing trend.
- **Use of surrogate data:** When a strong relationship between the parameter to be estimated and another indicator is known, then the indicator may be used as a 'proxy' to estimate the parameter.

Further guidance on the use of time series gap filling methods is given in Section **C.4 Methodological guidance**.

In some cases, there may be no data for the whole time series of a specific parameter. Section B highlighted the difference between the *parameters* required by the IPCC equations and the *data indicators* that can be used to estimate them (see **Methodological Focus B.1: The difference between parameters, indicators and activity data**).

It may also be possible to use alternative indicators together with available data to estimate values when the whole time series for a parameter is missing. The appropriate method depends on circumstances. Some potentially applicable methods include:

Combining multiple data sources: To estimate a given parameter, it may be necessary to combine data from different sources. For example, official statistics often only report the total population of each livestock type, but not the population of animal sub-categories. Official data on total population can be combined with survey data on herd structure to estimate the population of each sub-category. A worked example of how this has been done is given in **Worked example C.1: Estimating dairy cattle sub-populations in Kenya**. **Worked example C.3: Estimating a time series for live weight and mature weight in Kenya** also shows how one data source on the average live weights of different breeds was used together with other data sources on the proportion of breeds in the population to estimate a time series for live weight. **Worked example C.4 Interpolation of missing years in the population time series** illustrates that different methods for filling data gaps can be compared before choosing the most appropriate method.

Use of surrogate data or proxies: If a relationship between a parameter and another indicator variable is known, the indicator variable can be used as a 'proxy' to estimate the parameter. For example, live weight or milk yield may have a known relationship with farm type, feeding system, breed or other variables. These variables can then be used to estimate the target variable. A worked example of how data on breed was used to estimate live weight is given in **Worked example C.3: Estimating a time series for live weight and mature weight in Kenya**. Sometimes, these proxy variables can be used to produce an initial estimate to be replaced by better data in the future. But where the relationship between the proxy and target variables is well-founded and stable, the use of proxy variables can become a central part of how the inventory is structured. For example, the Republic of Georgia uses data on the characteristics of three main cattle breed types and an estimate of the proportion of each breed in the cattle population to produce annual estimates of the average value of each activity data parameter (see Livestock Characterization and Herd Structure Modeling in Georgia). Austria's GHG inventory uses data on the share of organic farming in total agricultural land area to estimate the proportion of cattle of each sub-type raised in organic and conventional farming systems, assuming that herd structure does not differ between the two farming systems (see Dealing with missing data for livestock characterization in Austria).

Extrapolation: It is common for some part of the livestock population to be better documented than others. If breeds, feeding system and agro-ecological conditions are similar, it may be justifiable to extrapolate activity data measured from one part of a population (e.g. a sample of calves in Region A) to a similar population (e.g. all calves in Region A). An example of this type of extrapolation is given in https://www.agmrv.org/knowledge-portal/case-studies/inventory-practice-estimating-milk-yields-in-slovenia/. However, extrapolation of data sampled from one region to another region where farming conditions differ is less reliable, because the second population is not part of the population from which the measured sample comes. Further guidance on the use of animal registries – which are often the best documented animals – is given in **Methodological Focus B.7: Using animal recording databases**. As with other gap-filling methods, extrapolation may be used to produce initial estimates that will later be improved, or extrapolation from a well-documented part of the population to another part of the population may become central to how the inventory is compiled on a regular basis.

IPCC default values: Some countries have compiled their initial Tier 2 inventory using IPCC default values for most parameters (for example, see a case study on Bulgaria's national inventory). The Tier 1 emission factors presented in the 2006 IPCC Guidelines were developed using parameter values that are given tables in Annex 10A.1 and Annex 10A.2 of Vol. 4 Ch. 10. The data presented in those tables are categorized by continental region, but production systems in a region may vary considerably. When selecting the appropriate default value for activity data, inventory compilers should inspect the animal characteristics such as live weight, weight gain and milk yield to ensure that the activity data values taken from these tables represents conditions similar to those in the country. The 2019 Refinement to the 2006 IPCC Guidelines further gives default values for both high and low productivity animals in each broad continental region, and the underlying data are reported in Annex 10A.1 in Vol. 4 Ch.10.

Similarly, inventory compilers can consult the underlying activity data reported in other countries' national inventory reports, and select values from similar production systems and animal sub-categories. **Tool D.2 Searchable database of activity data underlying Tier 2 emission factors** presents a web-based tool that contains a database of the activity data underlying the IPCC default emission factors as well as emission factors reported in countries' submissions to the UNFCCC. Even if there are some missing values for activity data, the user can input the available values and the tool will select the database entries most similar to the input values. The user can then refer to the original national inventory reports to assess whether the activity data represent similar production systems and animal sub-categories.

C.1.2 Collecting new data to fill data gaps

This section focuses on methods for data collection when there is no usable data at all, or when it has been decided not to use available data because of poor quality. The 2006 IPCC Guidelines (Vol. 1 Ch. 1) acknowledges that there may be trade-offs between the accuracy of inventory compilation and the availability of financial and human resources for data collection. It also defines good practice as maintaining inventories "in a manner that improves inventory quality over time". Inventory compilers may decide to fill data gaps using resources available within the timeframe of the inventory compilation activity, with collection of higher quality data planned for the future.

The 2006 IPCC Guidelines (Vol. 1 Ch. 2) describes general aspects of good practice in the collection of new data, which is summarized in **IPCC guidelines on collection of new data** Data should ideally derive from representative sample surveys, and should be collected using appropriate data collection methods that are fully documented. Sample surveys can often involve considerable costs. Integrating inventory data needs into surveys that are already planned by the statistics agency, livestock ministry or other stakeholders can reduce or share the costs of new data collection. Longer-term improvements in data collection are discussed in Section **E. Continuous improvement**. Using census sampling frames can ensure that the indicators derived from a survey are consistent with census estimates of other parameters. However, the target population of census and additional data collection activities may differ, and a tailored sampling method may be more appropriate. General guidance on sampling can be obtained from books on statistical sampling and resources on rural surveys and livestock surveys listed in **C.6 Additional resources**.

Appropriate methods for data collection will depend on the parameter of interest. For example, studies have often found that one-off questionnaire surveys that rely on farmer estimates often do not give accurate estimates of animal live weight. However, body measurements can easily be incorporated into household surveys. Recent activities by the Global Strategy on Agricultural Statistics have also demonstrated that good estimates of key livestock parameters can often be produced using lower-cost methods than the best quality ('gold standard') methods. Further information is given in **C.6 Additional resources**.

The following sub-sections describe common methods for collecting data on the key parameters in the IPCC equations. Considering resource constraints, alternative methods of data collection for use in the short-term are also presented. If the data gap relates to a whole production system or region, then integrated data collection methods can be effective in collecting data on multiple parameters at the same time. Two common integrated data collection methods are questionnaire surveys and expert judgement.

Questionnaire surveys: Key considerations include the sampling strategy, data collection tools and planning for survey implementation. Existing livestock survey tools used in the country may be suitable or provide a basis for adapting new survey tools. **C.6 Additional resources** provides links to guidance on sampling and data collection tools. IPCC (2006, Vol.1 Ch. 2) also provides general guidance on survey planning.

Expert judgement collection techniques: Some countries have compiled most activity data required for their initial inventory using expert judgement (see a case study on Canada's Tier 2 inventory). Expert judgement can be collected rapidly through stakeholder workshops, such as the regional workshops convened in Colombia. Expert judgement can also be obtained through questionnaire surveys to selected livestock experts, such as the surveys used to develop Canada's Tier 2 inventory. These questionnaires can be sent out to livestock experts in each part of the country, resulting in a national dataset for activity data. **Tool C.1 The Delphi Technique for eliciting expert judgement** describes a method for obtaining parameter estimates from experts when there is little or no data.

Livestock keepers and other livestock experts have a great deal of knowledge about the relationships between different factors. 'Rules of thumb', or broadly accurate estimates based on practical experience, are often used to guide livestock management. They may also be sufficiently reliable to use in compilation of an initial inventory. Such estimates can be updated in the future when better quality data becomes available. For example, if the average live weight of cows is known, livestock experts may be able to estimate the average weight of growing cattle and calves using common rules of thumb. A worked example is given in **Worked example C.2: Using 'rules of thumb' to estimate live weights**.

If data gaps relate to specific parameters or indicators, then the data collection methods in the following sections may be useful.

Livestock sub-category populations

Following a selection of herds for several years and measuring population and population dynamics is the 'gold standard' for collection of demographic data (including fraction of females giving birth). The Laser2 methodology, including questionnaires and data analysis software, has been developed by CIRAD. Data can be collected on herd demographics as well as animal production and reproduction traits. Application of the method, however, can be time and resource intensive. Questionnaire methods are more common. Guidance on livestock population sampling is given in Guidelines on Methods for Estimating Livestock Production and Productivity, published by the Global Strategy for Agricultural and Rural Statistics (GSARS). There are often particular challenges in obtaining population data in pastoral nomadic and semi-nomadic systems. Technical guidance and training materials have been developed by GSARS that involve a combination of ground survey (e.g. surveys at water points) and aerial surveys.

Live weight, mature weight and weight gain

Tool B.5 and **Tool B.6** suggested various potential sources of data on animal live weight. If none of these data sources are available or of sufficient quality, sample surveys can be used to obtain measurements. Because animal live weight is closely associated with age and sex or physiological status (e.g. intact, castrated), if animals of each sub-category defined by age and sex/physiological status are sampled at random, required sample sizes to achieve a given level of precision (e.g. 95% confidence ±10%) need not be large. **Worked example C.5 Estimating required sample size for a live weight measurement survey** illustrates the method for estimating required sample size based on a pilot survey.

Questionnaire surveys most likely do not provide accurate estimates of animal live weight. Among direct measurement methods, calibrated suspension scales or electronic scales provide the most accurate measurement of live weight. However, scales are often difficult to use in field conditions, especially for cattle. It is therefore common to use animal body measurements to estimate weight. For example, the heart girth (i.e. circumference around the body just behind the shoulders), body length and other body measurements may have a close relationship with live weight. These relationships may vary by breed so it is important to use relevant measurements and conversion equations for the target animals. The appropriate body measurement and conversion of the measurement (in cm) to live weight (in kg) should be based on published studies that compare measurements using scales to estimates based on body measurements. If the conversion from body measurement to live weight is not well-founded, considerable uncertainty is added to the live weight estimate. For cattle, general guidance on undertaking live weight measurements can be found in the ICAR Guidelines for Beef Cattle Production Recording. For sheep, body condition score can be a good proxy for live weight, but often requires an adjustment to account for some of the variation in live weight that is not explained by body condition score. Body condition score should therefore only be used where the relationship between body condition score and live weight, and any required adjustment, have been established. Various guides on body condition scoring for sheep (e.g. for Scotland, Canada, Australia) have been produced, with technical details and the interpretation of results varying between production systems, breed and other factors.

In the IPCC Guidelines, mature weight refers to the shrunk body weight (SBW) of cattle that have reached the age of maturity. For cattle, SBW can be estimated as live weight * 0.96 (NRC 1996). Mature weight can therefore be estimated from a sample survey that includes the weight and ages of a large sample of mature animals.

In experiments, weight gain can be measured as the difference between live weights at two points in time. Direct measurement of live weight at different points in time would give the most reliable estimate of live weight gain. However, a long time is needed until data become available. An alternative, therefore, is to conduct one survey of the live weight of animals at different ages, and to estimate weight gain as the difference between the average of animals of one age category and the average of animals of the next oldest age category divided by the number of days between each age category:

$$WG = \left(\frac{weight_{AG2} - weight_{AG1}}{days_{AG2} - days_{AG1}}\right)$$

where

$weight_{AG2}$ = average weight of animals in age group 2, kg

$weight_{AG1}$ = average weight of animals in age group 1, kg

$days_{AG2}$ = average age of animals in age group 2, days

$days_{AG1}$ = average age of animals in age group 1, days.

Milk yield, milk nutrient content and wool production

Tool B.9 suggested various potential sources of data on milk yield. If none of these data sources are available or of sufficient quality, repeated measurements and sample surveys can be used to obtain data. Guidelines issued by the International Committee on Animal Recording recommended methods for estimating milk yields of cattle and sheep/goats that involve repeated direct measurements. Milk production may vary across breeds, feeding system or other criterion, so milking cows of different breeds or feeding system can be selected for repeated measurement. Because milk yield can be strongly affected by the seasonality of fodder resources, repeated measurements may have to be undertaken at different times of year to obtain an accurate estimate of annual average daily milk yield. Long-term monitoring studies can be resource-intensive. Farmer questionnaire surveys are often used in place of direct measurements. Validation studies have found that questionnaire design may have a big influence on the accuracy of farmer recall estimates. Comparison studies have also found that different survey methods may incur different costs.

Milk fat and protein content

There are several standard methods for measuring milk fat content (e.g. Gerber butyrameter method, Röse-Gottlieb gravimetry method, acid digestion method) and milk protein content (e.g. Kjeldahl method, and direct or indirect protein testing methods). These methods are routinely used in milk quality testing and are well described in manuals for Milk Testing and Quality Control and other materials. Many countries have an agency responsible for milk quality testing or and milk chemical properties are often measured by milk processors. These agencies or companies, as well as university animal science departments, may have the required equipment and laboratory procedures for chemical analysis of milk. While random sampling of animals representing the targeted inventory category would be ideal, costs of sampling and laboratory analysis can be shared if data is collected as part of routine milk quality control activities.

Wool production

Wool production is measured at the time of shearing (or combing for goats). Shearing (or combing) is mostly done once a year, but some breeds are shorn twice a year. Data collection should be timed to coincide with the usual timing of shearing in order to be representative. Directly sheared wool is referred to as ‘greasy wool’. Greasy wool should be cleaned to remove foreign matter and dried, or a fixed coefficient from the literature for dry matter content of wool applied to the greasy wool weight. Specific guidance on sampling within herds is given in FAO Guidance on Collecting Livestock Data.

Feeding situation and activity

In mixed stall-grazing systems, the coefficient for activity (Ca) can be weighted by the number of days in stall and grazing (see **Worked Example B.6: Calculating a weighted average activity coefficient**), and the key activity data to collect is the number of days spent grazing in a year. This is often collected as part of a farm survey that also collects data on farm operations, feeding practices, and/or types of housing and manure management systems.

In more extensive grazing systems, if the need is to determine an appropriate value of Ca, then data on grazing distance should be collected, ideally together with animal weight estimates (see **Methodological Focus B.11: Calculating an appropriate value for the coefficient for activity.**). The most common method to measure grazing distance is by using GPS collars. Rough estimates of grazing distance can also be obtained using interview methods and participatory mapping. These methods can also be used together with botanical sampling to determine feed composition.

Feed composition and digestibility

One way to estimate feed composition is based on feed availability. Measurement methods depend on the types of fodder and feed involved. For cultivated fodder, crop cutting experiments can be used to estimate crop yield and survey data on the area of fodder under each crop used to estimate total crop output. More guidance on these methods are given in FAO Guidance on Collecting Livestock Data. FAO has also developed guidance on conducting national feed assessments, which summarizes several methods for estimating both available feed and livestock feed demand.

In stall-fed livestock systems, direct measurements of fodder and feed as-fed, and dry weight measurement of a sample of feedstuffs, is the most accurate way to estimate animal diets. However, this is very labour intensive. Information on feeding practices is often collected using questionnaire surveys. Another rapid method is the Feed Assessment Tool (FEAST) developed by ILRI. FEAST mainly relies on participatory group discussions with livestock keepers to estimate diet composition. Digestibility of the resulting diet is estimated using a dataset in the tool. By using participatory discussions, the cost of implementing a feed assessment using FEAST is most likely lower than the cost of questionnaire surveys. However, questionnaire and participatory methods can result in errors that are difficult to quantify, due to the use of farmer recall and uncertainties in the conversion of local mass and volume units into kg dry matter.

For grazing systems there are various methods to quantify animal diets. Ground and aerial surveys or remote sensing together with ground-based forage sampling can be used to characterise and estimate available feed resources, and several methods are summarized in FAO guidance on conducting national feed assessments. Diets can also be quantified using various methods for analysing animal faeces, such as micro-histology, near infrared spectroscopy or n-alkane analysis.

Once typical diets have been identified, feed nutrient content (feed digestibility and crude protein content) can be measured from feed samples using standard laboratory techniques and energy conversion factors. These are set out in several manuals, such as the Animal Nutrition and Product Quality Laboratory Manual published by ICARDA.

Manure management systems

Data on manure management systems is most often collected using questionnaire surveys. Animal housing systems determine the main manure characteristics, and different systems of housing and flooring characteristics are often associated with different manure management practices. So manure management surveys may record the housing type and housing characteristics as well as manure management practices used. Data can then be analysed to characterise the distribution of manure between different management systems on different types of farm or in different regions. Care should be taken to align the manure management categories in the questionnaire with the IPCC categories in ways that are easy for farmers to understand. Detailed description of different manure management systems common in tropical countries can be found in a manual on manure management systems in the tropics published by Wageningen University & Research Centre. There is no existing comprehensive guidance on the conduct of manure management surveys. A description of one such survey conducted for a national inventory is available for Austria. Examples of other surveys can be found in the scientific literature, or in the survey tools used in farm input and farm business surveys, such as those used in the European Union and Canada.

C.2 IPCC Guidelines and UNFCCC Decisions

IPCC Guidelines and UNFCCC decisions on time series consistency

UNFCCC COP 8 (2002) adopted revised guidelines for the preparation of national communications by Non-Annex I Parties (Decision 17/CP.8), which required Non-Annex I Parties to prepare an initial national GHG inventory for the year 1994 (or optionally 1990), and a second inventory for the year 2000. COP 16 (2010) agreed that developing countries should submit national communications every four years, and a Biennial Update Report (BUR) every two years (Decision 2/CP.17, Annex III), in which "each Non-Annex I Party is encouraged to provide a consistent time series back to the years reported in the previous national communications". The Annex to Decision 18/CMA.1, Modalities, Procedures and Guidelines on transparency in the Paris Agreement, states:

> "Each Party shall report a consistent annual time series starting from 1990; those developing country Parties that need flexibility in the light of their capacities with respect to this provision have the flexibility to instead report data covering, at a minimum, the reference year/period for its NDC under Article 4 of the Paris Agreement and, in addition, a consistent annual time series from at least 2020 onwards".

Consistency is one of the key criteria for GHG inventory quality (IPCC 2006, Vol. 1 Ch. 1). To achieve consistency, annual GHG emission estimates should, as far as possible, be calculated using the same methods and data sources in all years. This is so that the trend in emissions reflects real changes, and not changes due to the estimation methodology. For initial inventories, this means that consistent methods and data sources should be used to calculate the whole time series back to the inventory base year. If improvements in methodology or data sources are subsequently made, then the whole time series should be recalculated to ensure that it remains consistent. Specific guidance on time series consistency is given in IPCC 2006 Vol.1 Ch. 5 and in the corresponding chapter of the 2019 Refinement to the 2006 IPCC Guidelines.

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IPCC guidelines on gap filling methods

The 2006 IPCC Guidelines (Vol.1 Ch. 5) provides guidance on methods that can be used to fill gaps in time series data. Methods described therein include the overlap technique, use of surrogate (or proxy) data, interpolation and trend extrapolation. The 2019 Refinement also describes non-linear trend analysis methods. Vol.1 Ch. 5 Table 5.1 provides advice on when each method may be suitable. The use of these methods is also recognized in the Modalities, Procedures and Guidelines on transparency in the Paris Agreement (Annex, para. 27).

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IPCC guidelines on collection of new data

IPCC guidelines on collection of new data (Vol. 1 Ch. 2) highlights the following aspects of good practice:

- Collection of new data should be focused on key categories to prioritize the use of resources;
- As far as possible, link new data collection to existing data collection activities (e.g. surveys already planned by national statistics agency or the relevant ministry), so as to optimise the use of inventory resources;
- plan each step in a survey process from data collection, processing and analysis to dissemination of output;
- Ensure a representative sample and the use of appropriate measurement methods;
- Clearly document the measurement methodology;
- Give clear instructions to the people doing the measurements;
- Document how the measurement data is processed.

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IPCC guidelines on eliciting expert opinion

When alternative data sources are not able to provide the data needed, it is good practice to use expert judgement (IPCC 2019, Vol. 1 Ch. 2). There may be some available data to inform expert estimates, such as data from other countries with similar conditions or sub-national data. A protocol for expert elicitation and a template for documentation of expert judgement are provided in IPCC 2006 (Vol. 1 Ch. 5, Annex 2A.1).

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C.3 Useful tools

Tool C.1 The Delphi Technique for eliciting expert judgement

Expert judgement can be applied in different ways. In some cases, various data sources are available, but none is fully representative, so the most appropriate data values are selected on the basis of analysis of the available data through expert judgement. An example is provided by a case study where expert judgement was applied to available data for estimating cattle live weight in New Zealand's inventory. In other cases, data on specific parameters is entirely lacking, and data values can be estimated by expert judgement. Sometimes, there will be few experts with knowledge of the likely values of the parameter of interest, and the protocol for expert elicitation given in the 2006 IPCC Guidelines can be applied with one or more individuals. In situations where there is very limited recorded data, and several experts have knowledge of the parameter of interest, the Delphi Technique may be a useful way to generate a consensus value.

The Delphi Technique assumes that a group of experts is more likely to provide a better estimate of the parameter value than an individual expert. It involves the following steps:

1. Form a panel of experts.
2. Phrase a question that clearly states what value is being sought (e.g. value for which parameter) under what conditions (e.g. for which production system and animal sub-category, in which region) and ask the question to the experts requesting also justifications for the answer they give.
3. Experts return their estimates together with their justifications. Analyse the answers, and summarize the estimates received (e.g. mean, median, mode, standard deviation, justifications for extreme estimates, and any graphical representations that may be useful).
4. Provide the analysis of first round answers to the experts, and ask them to review their estimates in view of the feedback given. This step can be repeated until a satisfactory level of consensus has been reached.

For further information on the steps involved and related assumptions, there are numerous online materials and publications.

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C.4 Methodological guidance

This section provides guidance on the use of three methods for filling gaps in time series:

Methodological Focus C.1: Interpolation

Methodological Focus C.2: Trend extrapolation

Methodological Focus C.3: Use of surrogate data

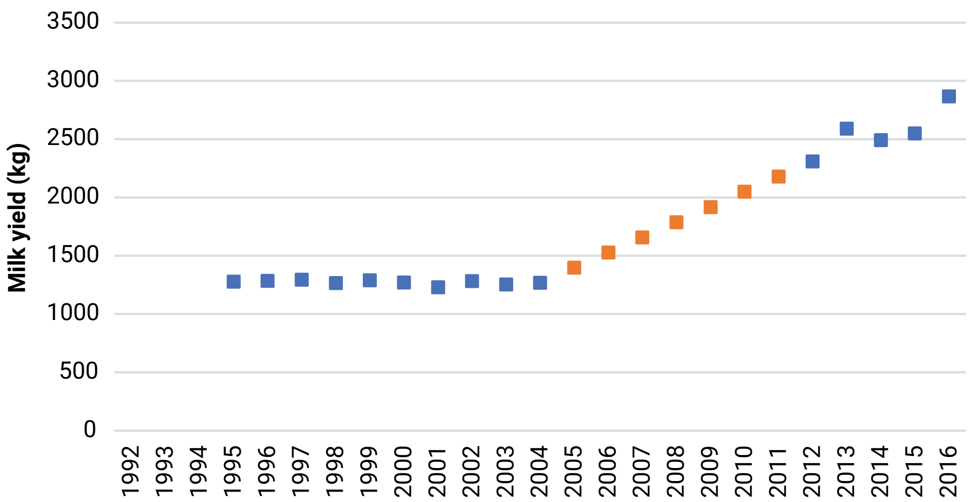
Methodological Focus C.1: Interpolation

If there are gaps in a time series (e.g. because data were not collected annually) and the available data indicate a clear trend, interpolation may be an appropriate method. Linear interpolation would not be appropriate if the data is highly variable from year to year. Figure 14 shows hypothetical milk yield data for the period 1995-2016, with missing data for 2005-2012 filled using linear interpolation. Here, the imputed annual average increase in milk yield (MY) is calculated as:

$$\Delta MY = \frac{(MY_{2012} - MY_{2004})}{(2012 - 2004)}$$

In the example here, linear interpolation is used. If the trend is not linear, then non-linear interpolation methods may be used, and justification should be given for the methods chosen. Guidance on non-linear trend analysis is given in the 2019 Refinement to the 2006 IPCC Guidelines (Vol. 1 Ch. 5).

Figure 14: Example of linear interpolation to fill a gap



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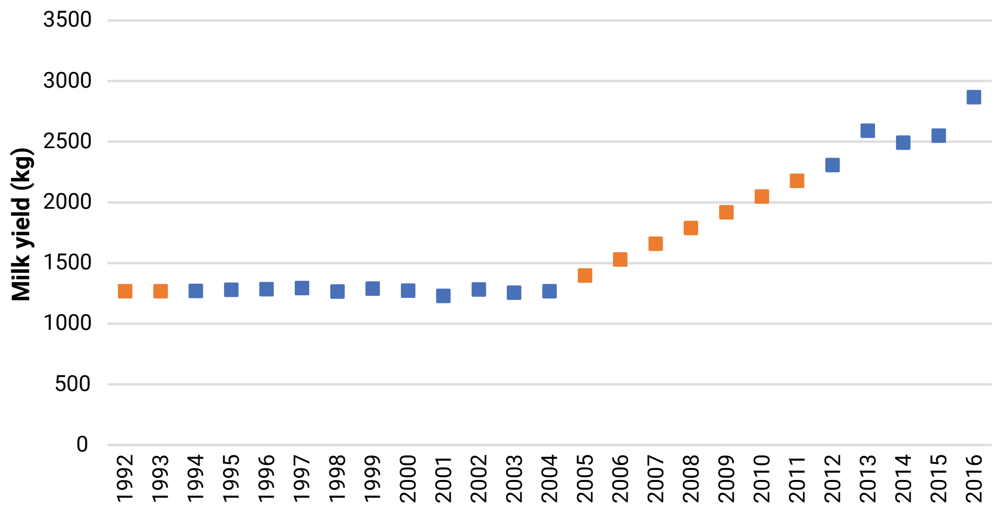
Methodological Focus C.2: Trend extrapolation

Another situation where data gap filling methods may need to be used is when a time series does not extend back to the base year in the inventory. If there is a clear trend in existing data, this trend can be extended back to the base year. An example is shown in **Figure 15** where the annual average percent change between 1994 and 2004 (i.e. ca. 0.02%) is extrapolated to data for 1992 and 1993. If the trend is not linear, non-linear interpolation methods may be used, and justification should be given for the methods chosen.

Figure 15: Example of linear extrapolation to fill a data gap



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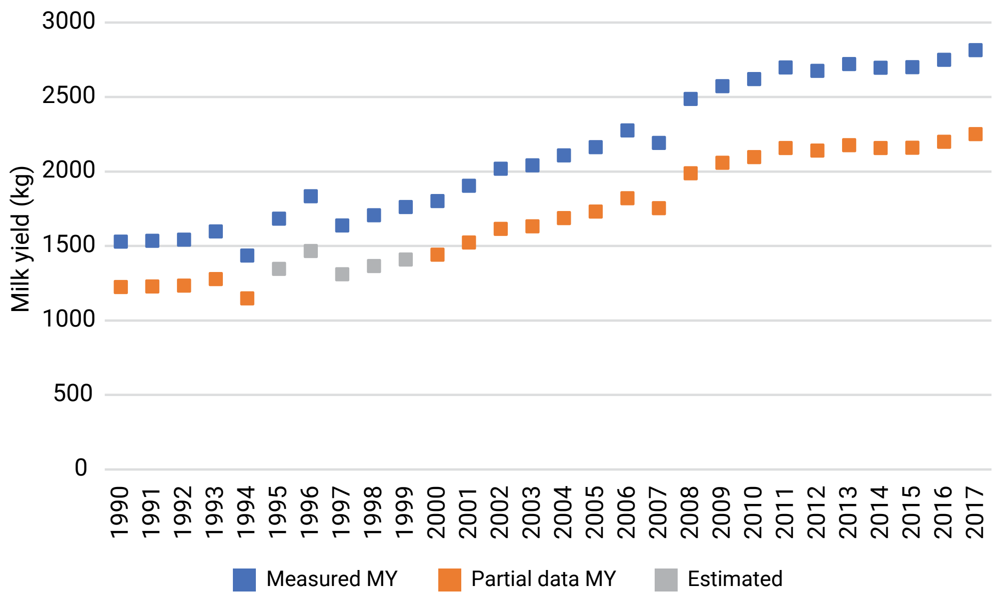
Methodological Focus C.3: Use of surrogate data

Surrogate data may be used to estimate missing data if a relationship has been established between existing data and a surrogate dataset. An example is shown in **Figure 16**. In that example, a full time series of milk yield data is available for one portion of the cattle population ('Measured data'), but for another category of cattle data is only available for 1990 – 1994 and for 2000 onwards ('Partial data MY'). For years where both datasets are available, analysis shows that Partial Data MY is roughly 80% of the value of 'Measured data'. Using this relationship, the missing years are filled in using (0.8 X Measured data) as a surrogate for the missing values. It may be appropriate to use surrogate data to fill data gaps when the relationship between two time series is relatively stable and well known.

Figure 16: Example of using surrogate data to fill a data gap



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C.5 Worked examples

Worked example C.1: Estimating dairy cattle sub-populations in Kenya

Administrative data collected by counties in Kenya records the total population of dairy cattle. The inventory needed to estimate the population of five sub-categories:

- Cows
- Heifers
- Adult males
- Growing males
- Calves

A review of scientific publications, project reports and other grey literature was done to compile all available reports of the percentage of each sub-category in the herd (Table 16). The identified data sources included representative regional samples as well as small-scale studies in particular locations, and referred to different years. The reports also used different categories. Some reported bulls and oxen separately, while others only reported for bulls. In this case it is assumed that this includes both bulls and oxen. All reports listed male and female calves separately. To estimate the average herd structure in the semi-intensive region, the average from all studies was calculated weighted by the sample size of each study. These percentages were applied consistently to all years in the inventory given the lack of data on changes in herd structure over time.

Table 16: Available data on herd structure in semi-intensive production systems in Kenya

Source	A	B	C	D	E	F	
Year	2000	2006	2012	2011	2013	2012	
survey type	regional survey	1 sub-county	3 peri-urban sites	regional survey	2 counties	2 counties	Weighted average
sample size	1575	236	75	341	400	151	
Bulls	6%	-	13.20%	6.59%	1.80%	7.40%	
Oxen	6%	-	-	5.65%	-	-	
sum adult males	*12%*	*-*	*13%*	*12%*	*2%*	*7%*	*9.32%*
Growing males	12%	17.72%	5.60%	-	5.70%		9.28%
Cows	26%	24.00%	46.40%	38.87%	48.40%	53.79%	32.70%
Heifers	22%	22.42%	16.40%	20.40%	17%	12.45%	20.45%
Calves	*28%*	*36%*	*18%*	*28.49%*	*27%*	*26.35%*	*28.25%*
Male calves	13%	17.10%	5.60%	-	12.10%	-	
Female calves	15%	18.75%	12.80%	-	15%	-	

Note: Regular typeface is taken directly from each report. Italics indicates that the figure has been calculated from the values for sub-categories in each report.

The inventory reports male and female calves as one category. But the IPCC default coefficient for growth (C) is different for males and females. The weighted average ratio of male to female calves shown in the table were used to estimate a weighted average coefficient. Similarly, the coefficient for maintenance (Cf_i) is different for bulls and oxen, and the weighted average of the two reports shown in the table were used to estimate a weighted average coefficient.

The inventory improvement plan prioritizes conducting a regionally representative survey to collect data on herd structure consistent with the inventory categories. When that data is available, the herd structure in the time series may be revised.

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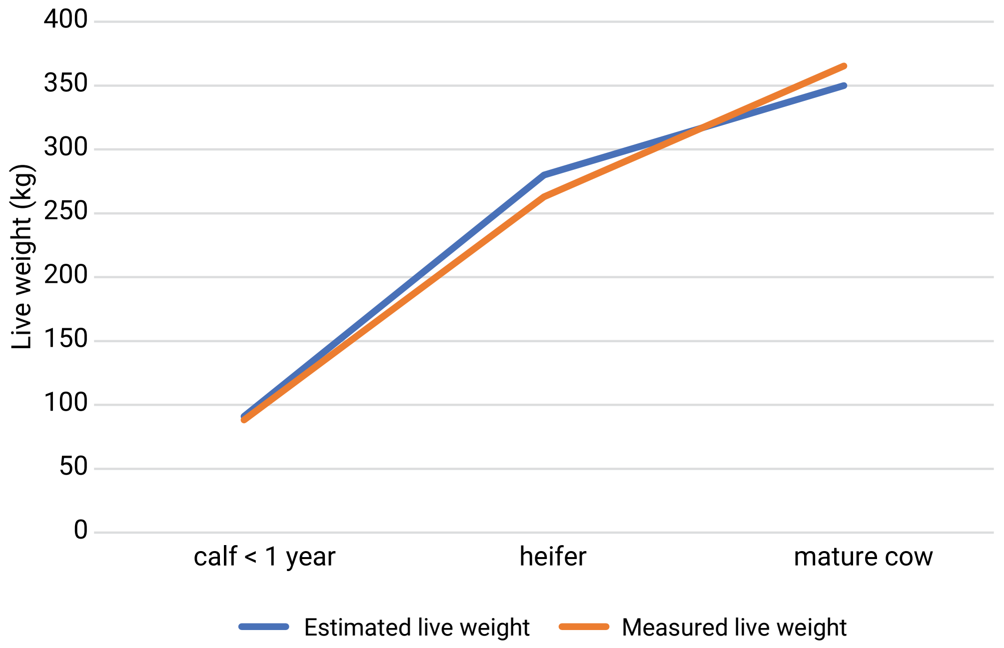
Worked example C.2: Using 'rules of thumb' to estimate live weights

If live weight estimates are available for one sub-category, but not for other sub-categories, then live weights can be estimated using rough guidelines, known as 'rules of thumb'. For example, in the first draft of Kenya's Tier 2 dairy cattle inventory, a livestock expert estimated that heifer live weight at 2 years old would be about 80% of cow weight, and calf birth weight would be about 8% of cow weight. Calves are defined as those below 1 year of age; heifers are females >1 year and <3 years old and cows 3 years and older. Live weights were calculated as follows:

1. Cow weight was estimated at 350 kg.
2. Heifer weight is 80% of mature cow weight: 0.8 X 350 = 280 kg
3. Calf birth weight is 8% of cow weight: 0.08 X 350 = 28 kg
4. Assuming linear growth to the age of 2 years old (i.e. 730 days), average daily weight gain would be (280-28)/730 = 0.345 kg per day
5. If calves are between 0 and 1 year old, the median age is 182.5 days, so 28 + (182.5 X 0.345)= 91 kg.

Figure 17 shows the live weights estimated using these rules of thumb compared to the actual live weights reported from a sample survey.

Figure 17: Live weight estimates using 'rule of thumb' and measured data



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Worked example C.3: Estimating a time series for live weight and mature weight in Kenya

For some livestock sub-categories, genetics and management practices have changed little over time. It may therefore be appropriate to apply the same literature or survey data value for live weight to the whole time series. But for some animals, such as dairy cows, improved genetics or management may lead to an increase in average live weights over time.

A literature review identified one source of live weight measurements in the intensive system in Kenya, with measurements conducted in 2018. This source provided live weight estimates for each sub-category of animal by breed. From the 2018 dataset, it was found that the live weight of Friesian and Ayrshire cows (mean 379.58 kg) was significantly different from the average live weight of cows of other breeds (mean 323.52 kg). Two other sources were identified for estimates of the proportion of different breeds in the herd in 1998 and 2008, respectively. The average live weight of cows in 1998, 2008 and 2018 was calculated as the weighted average of different breeds (Table 17). The same average live weights for cows of different breed types in each year, were applied to the proportion of each breed type in 2018, 2008 and 1998. The 2018 data also showed that average live weight in the herd was 98% of mature weight, and this was applied consistently in each year. Live and mature weights in intervening years were linearly interpolated.

Table 17: Estimated mean live weight and mature weight of dairy cows in Kenya, 1998-2018

	1998	2008	2018
% Friesian or Ayrshire in herd	72%	87%	89%
% other breeds in herd	28%	13%	11%
Weighted average live weight (kg)	356.63	365.07	366.12
Weighted average mature weight (kg)	363.68	372.28	373.35

The resulting estimate for 1995 was cross-checked against one available scientific paper that reported a small number of measurements of live weights on smallholder farms in 1995, and the estimated live weight compared well with the value reported in that study.

This method assumes that the average live weight of each breed type has not changed over the time series.

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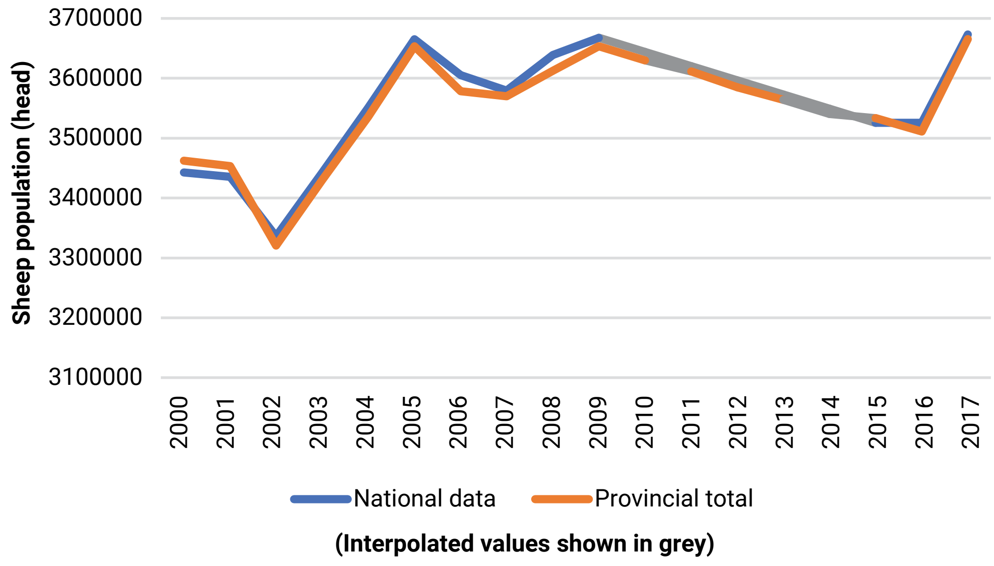
Worked example C.4 Interpolation of missing years in the population time series

In country X, national data on the population of sheep is incomplete due to poor archiving of data at national level. The inventory needs data for every year from 2000 to 2017, but there is missing data for 2010-2014. To fill the data for 2010-2014, two methods were used and compared. First, linear interpolation was used to fill missing years in the national population time series (see Figure 18). Second, available data from each province in the country was used to make a 'bottom up' estimate of the total. Provincial data was also missing for some years. For years with provincial data, the average proportion of each province in the national total was calculated and this was used to estimate the population in provinces with missing data. The two estimation methods were compared. The result was similar, but not identical. It was decided to use the linear interpolation method because it relies on fewer, more transparent assumptions.

Figure 18: Comparison of alternative methods for interpolating missing values



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Worked example C.5 Estimating required sample size for a live weight measurement survey

The required sample size (n) when simple random sampling (SRS) is used can be calculated using Equation 1:

$$n \geq \left[\frac{z_{\alpha/2}\sigma}{E}\right]^2 \qquad \text{(Eq. 1)}$$

where

- $z_{\alpha}/2$ The z-score separating an area of α/2 in the right tail of the standard normal distribution (for 95%, the z-score is 1.96)
- σ Standard deviation of live weight (kg)
- E Allowable margin of error around the mean (e.g. 10%)

The margin of error is sensitive to the standard deviation of measurements, the required precision and the confidence level (alpha), and relatively less sensitive to the population size (N). However, random sampling of a production system or a large region of a country can be expensive in terms of travel costs and enumerator time. Therefore, two-stage cluster sampling is often used: first, enumeration areas are selected at random within the region, then clusters of households are sampled at random in each enumeration area. With cluster sampling, the required sample size should take account of both the variation between households and the variation between clusters, by calculating the design effect (DEFF):

$$DEFF=1+(m-1)\rho$$

where *m* is the average number of households in a cluster and ρ is the intra-cluster correlation coefficient, which measures the ratio of variability between clusters to variability within clusters. The calculated value of DEFF is used to adjust the sample size estimated using SRS to account for the effect of the cluster sampling method. Sample size may also need to be adjusted for eligibility (e.g. what proportion of sampled households keep the target animal type) and for non-response.

A survey was conducted in the region of Kenya where dairy production is relatively more intensive, and sampled over 400 households in 41 clusters of 10 households each. Data was collected using a questionnaire on several parameters required for GHG estimation, and in each household one animal of each sub-category was measured using a heart girth tape to estimate live weight. Subsequent analysis of the live weight data estimated the required sample size using Equations 1 and 2, and adjusting sample size for the proportion of households keeping each type of animal. Estimated required sample sizes for cows and heifers, which together make up more than 70% of all dairy cattle enumerated in the survey, are shown in Table 18. For both cows and heifers the estimated value of DEFF was about 3.9. That is, compared to pure random sampling in the region, the cluster sampling method used requires that almost 4 times as many households are sampled. The required sample sizes for cows is smaller than for heifers, primarily because the average household sampled keeps at least one cow, whereas only about 60% of households keep a heifer. For animal sub-categories that are kept by few households, such as oxen, sample sizes would be much greater.

Table 18: Estimated sample sizes (number of households) for measurement of cattle live weight to given precision levels with a 95% confidence interval in central Kenya

	Target precision level	
	±5%	±10%
Sample sizes for cow live weight	75	28
Sample sizes for heifer live weight	1080	285

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C.6 Additional resources

CGE Training materials for the preparation of national communications from non-Annex 1 Parties contains training modules on approaches to data collection and time series consistency

On sampling strategy and survey design:

UN FAO (2012) Guidelines for linking population and housing censuses with agricultural censuses with selected country practices

UN FAO (1996) Conducting Agricultural Censuses and Surveys

UN FAO (1989) Sampling Methods for Agricultural Surveys

Practical worked examples of sample size, reliability and precision calculations are given in a document produced for the Clean Development Mechanism of the UNFCCC: Sampling and surveys for project activities and programme of activities

On data collection methods:

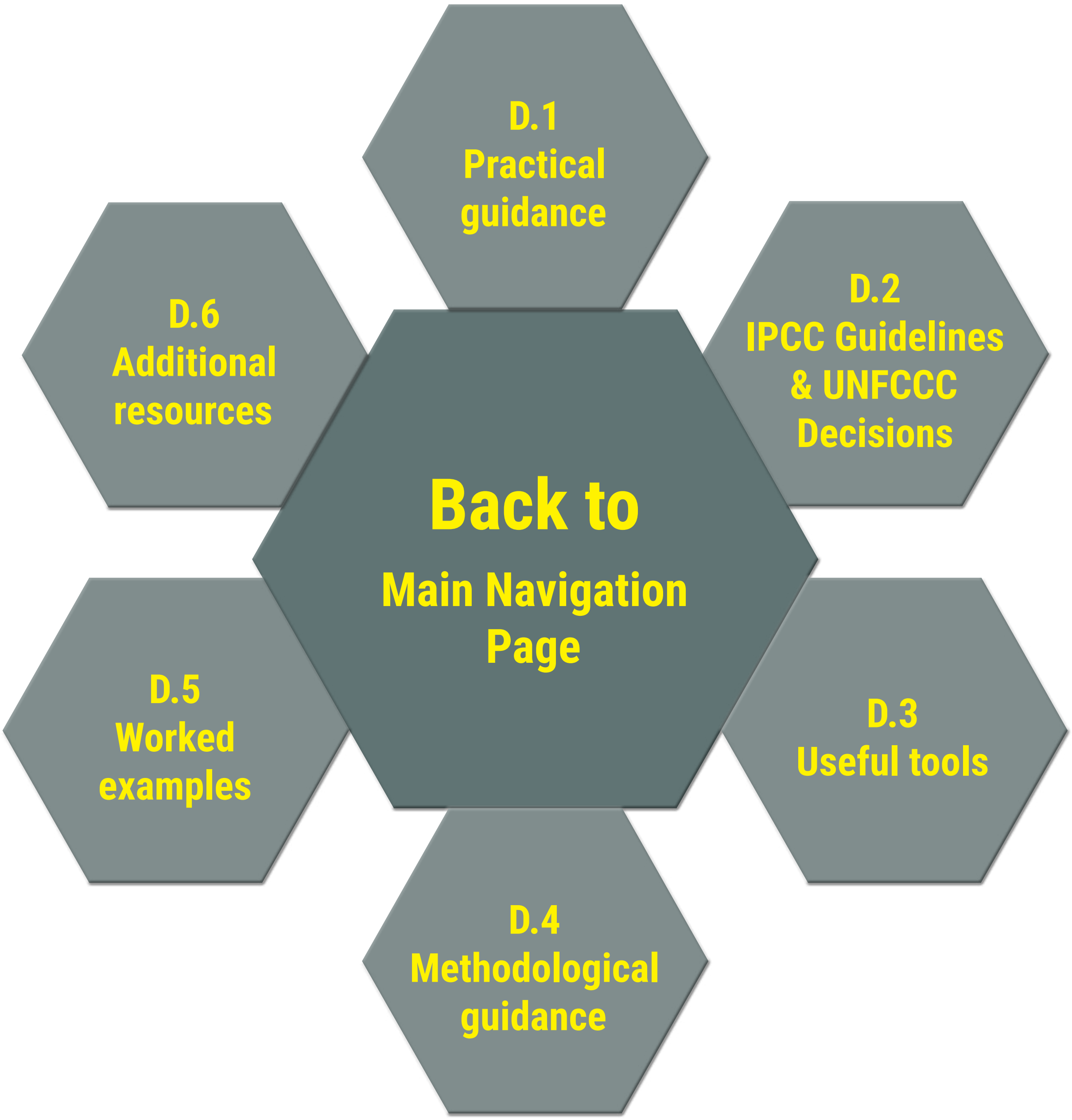
UN FAO (1992) Collecting Data on Livestock

LSMS (2016) Measuring the Role of Livestock in the Household Economy

The Global Strategy for Agricultural and Rural Statistics has produced a range of publications on collection of livestock data, including:

GSARS (2018) Guidelines on methods for estimating livestock production and productivity and a related training course; and reports comparing existing and alternative methods for collection of livestock data. For a full list of GSARS publications on livestock see http://gsars.org/en/tag/Livestock/

D. Documentation and inventory quality assessment



D.1 Practical guidance

When compiling the inventory, the IPCC Guidelines require transparent **documentation**, the application of **quality control/quality assurance** and **verification** activities, and **archiving** of all relevant documentation. Uncertainty analysis is also part of the IPCC good practice guidance and guidelines. Uncertainty analysis can be an important source of information on priorities for continuous improvement. To support the identification of priorities for continuous improvement, these guidelines also provide a tool to support qualitative analysis of data quality that can be used to identify priorities for improvement.

D.1.1 Documentation

Transparency is one of the key principles for good practice in GHG inventory compilation. In general, transparent documentation should enable readers to assess compliance with the principles of transparency, accuracy, completeness, comparability and consistency, and the extent to which the inventory was compiled using methods consistent with the IPCC Guidelines. Transparent documentation and archiving of documentation are also vital for the institutional sustainability and consistency of inventory practices over time, so that as individual staff changes, subsequent inventory compilers can easily see how earlier inventories were compiled. An overview of good practice in documentation of Tier 2 emission calculations is given in **IPCC good practice in documentation of Tier 2 livestock emission estimates**.

To support transparent documentation of Tier 2 livestock inventories, **Tool D.1: Suggested structure for Tier 2 livestock inventory report** provides suggested templates for documentation of an initial Tier 2 inventory. The templates include:

- A suggested structure for an inventory report. This template is based on the structure of the national inventory report outline for Annex 1 countries. While this structure is not obligatory for developed countries, it is useful to support transparent reporting.
- A set of suggested tables for reporting of the activity data underlying emission factor estimates. This template is based on tables used by some developed countries in their national inventory reports, and has proven useful for supporting transparent reporting of the data used to derive emission factors.

Considering the specific needs of each inventory, inventory compilers may also adopt other reporting formats in place of or in addition to these templates. It may also be useful to view examples of other inventory reports from developed or developing countries, so that inventory compilers can decide on formats they feel are most transparent and that suit national conditions.

D.1.2 QA/QC and verification

IPCC definitions of quality control (QC), quality assurance (QA) and verification are summarized in **IPCC definitions of quality control, quality assurance and verification**. **QC** is a system of technical activities conducted to assess and ensure the quality of the inventory as it is being compiled. QC activities involve numerous checks to ensure that there are no errors or omissions. For example, it involves checking the transcription of numbers from the original data source to the inventory software, or from the software to the inventory report. QC is normally conducted by a person working in the inventory compilation team, but not by the person who actually inputs the data into the inventory software and or the person who writes the inventory report. This is so that QC activities serve to cross-check the work of the inventory compiler(s). **QA** involves audit or review activities conducted by people that were not directly involved in inventory compilation. QA activities check that QC activities were conducted and documented, and make other checks to ensure that the inventory meets the required quality standards. **Verification** – checking inventory data and estimates against estimates from other sources – is a common QA activity. An overview of good practice in QA/QC of Tier 2 emission calculations is given in **IPCC good practice in QAQC and verification of Tier 2 livestock emission estimates**.

The 2006 IPCC Guidelines (Vol. 1, Ch. 6) also state that it is good practice to prepare a QAQC Plan. The QAQC plan should describe the QAQC activities that will be conducted, roles and responsibilities, and a timeline for QAQC activities in each year. The activities in the plan aim to ensure that the data quality objectives of inventory compilation have been met, and that it is delivered in a timely way. QAQC plans from Ghana and Cyprus provide useful examples of QAQC plans for national inventories and clearly show which activities are generally applied to the inventory as a whole and which are applied to specific sectors, such as livestock.

Based on a checklist given in the 2006 IPCC Guidelines (Vol 1. Ch.6), the LEDS Global Partnership has produced a template for comprehensive documentation of inventory QAQC activities. Drawing on that template, **Tool D.3 Checklist for general quality control activities** provides a checklist of quality control activities that are directly relevant to activity data compilation for Tier 2 livestock inventories.

One aspect of QC is to check the quality of the datasets and data used (IPCC 2006 Vol. 1 Ch. 6 Box 6.3). In section **B. Assess data availability and quality**, **Tool B.16** provides a spreadsheet to enable the assessment of data quality against the IPCC criteria for inventory quality. That tool includes a 'Summary' worksheet which provides a visual summary of which quality criteria have been scored higher or lower, and which parameters have been estimated with higher or lower quality (**Figure 19**). The summary results and the worksheets for specific data sources can be used by inventory compilers to ensure that data quality for all data sources has been assessed. The summary sheet can also be used to identify which parameters have been estimated using lower quality data, as an input into developing an inventory improvement plan. A worked example is given in **Worked Example E.1 Application of data quality analysis**.

Verification: IPCC (2006) Vol. 1 Ch. 6 states that verification refers to methods that "apply independent data, including comparisons with inventory estimates made by other bodies or through alternative methods". Verification, by comparing inventory estimated values with values from other sources, can help establish the reliability of the inventory. Often, this is done as part of QA activities. Livestock population data are often verified against livestock numbers reported in FAOSTAT. Countries commonly compare estimated values for emission factors and activity data with IPCC default values; with values reported in

Figure 19: Visual output from dataset quality assessment spreadsheet

		Production system A						
		Transp.	Accuracy	Accessibil	Compl. &	Comparat	Timeliness	sum (out of 24)
	Summary score	3.03	2.80	3.83	3.48	3.53	1.83	18.51
		Transp.	Accuracy	Accessibil	Consist	Comparat	Timeliness	sum
herd structure	mature dairy cow	4.00	4.00	4.00	4.00	4.00	2.00	4.00
	heifer	4.00	4.00	4.00	4.00	4.00	2.00	
	mature male	4.00	4.00	4.00	4.00	4.00	2.00	
	growing males	4.00	4.00	4.00	4.00	4.00	2.00	
	calves	4.00	4.00	4.00	4.00	4.00	2.00	
% milking		4	2	1	3	1	1	2.2
milk yield		1	2.5	4	2	4	3	2.70
Live weight	mature dairy cow	4.00	4.00	4.00	4.00	4.00	2.00	4.00
	heifer	4.00	4.00	4.00	4.00	4.00	2.00	
	mature male	4.00	4.00	4.00	4.00	4.00	2.00	
	growing males	4.00	4.00	4.00	4.00	4.00	2.00	
	calves	4.00	4.00	4.00	4.00	4.00	2.00	
Weight gain	mature dairy cow	1.00	3.50	4.00	4.00	4.00	3.00	3.24
	heifer	4.00	1.00	4.00	4.00	4.00	1.00	
	mature male	1.00	2.50	4.00	4.00	4.00	1.00	
	growing males	4.00	1.00	4.00	4.00	4.00	1.00	
	calves	1.00	1.90	4.00	4.00	4.00	3.00	
% pregnant	mature dairy cow	4.00	2.50	3.00	4.00	2.00	3.00	3.10
milk fat content		4	1	4	3	4	1	3.2

neighbouring or similar countries' GHG inventories; or with values published in the scientific literature. The IPCC Emission Factor Database can also potentially be used for verification. **Tool D.2 Searchable database of activity data underlying Tier 2 emission factors** is a web-based interactive tool that can be used by inventory compilers to compare the activity data underlying Tier 2 enteric fermentation emission factors with values in a database of over 150 Tier 2 applications for cattle. The database includes activity data used by the IPCC to develop Tier 1 default emission factors for enteric methane, as well as the activity data used in a large number of submissions by Parties to the UNFCCC.

D.1.3 Archiving

Archiving of data and documentation is important because it ensures that there is a basis for subsequent inventories. Each inventory system should have its own archiving procedures. In general, items that should be archived include the inventory report and the software with the underlying calculations, any methodology descriptions, references, expert opinions and other documents produced in the inventory compilation process. Documentation of QA, QC and verification activities should also be archived, as this provides an input into continuous improvement of the inventory.

D.1.4 Uncertainty analysis

Uncertainty assessment is an important aspect of good practice as described in the 2006 IPCC Guidelines (Vol. 1, Ch.3). Awareness of the uncertainty of parameter values can be used to evaluate whether data is suitable for use in the inventory. Analysis of uncertainty can also be used to identify parameters and activity data that contribute most to overall uncertainty of the inventory. This information can be used to prioritise inventory improvements. Because inventory compilers are rarely also statisticians, uncertainty analysis is often conducted by experts under contract to the inventory compilation agency. Sensitivity analysis is a simpler method than uncertainty analysis and can be useful in inventory compilation, but is not a replacement for uncertainty analysis (see **Methodological Focus D.1: Difference between sensitivity analysis and uncertainty analysis**).

The IPCC Guidelines quantify uncertainty as the margin of error given a 95% confidence interval of the emission estimate, e.g. ±20% or ±5%. For further guidance see **Methodological Focus B.2: Summary statistics and confidence intervals**. At a minimum, uncertainty should be quantified and reported for each emission category, e.g. enteric fermentation, manure management methane emissions. If a Tier 2 approach is applied to specific livestock types, it is useful to estimate the uncertainty for each livestock type. The IPCC guidelines suggest to calculate the uncertainty for an emission estimate in the year of the inventory, and an estimate of the uncertainty in the trend in emissions over time. This latter can be calculated as the uncertainty of the difference between emissions in the most recent inventory year and emissions in the inventory base year (e.g. 1990 or 1994).

IPCC guidelines on uncertainty analysis sets out two main technical approaches for calculating the uncertainty of an emission estimate. Approach 1 uses error propagation to calculate the overall uncertainty of estimated emissions for a given source. Approach 2 uses Monte Carlo simulation to estimate the overall uncertainty of estimated emissions. Many countries that use a Tier 2 approach for livestock have devoted relatively little effort to uncertainty analysis. The most common approach used to estimate the uncertainty associated with Tier 2 livestock emission estimates involves:

a. A country-specific estimate of activity data uncertainty (e.g. an uncertainty estimate supplied by the national statistical agency);
b. The default emission factor uncertainty noted in the IPCC Guidelines https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf (Vol. 4 Ch.10 pages 10.33, 10.48, 10.66);
c. Propagation of errors using Approach 1.

A worked example using IPCC default uncertainty estimates is given in **Worked Example D.1 Estimating uncertainty using error propagation**. While this approach does provide an estimate of uncertainty, it does not provide a great deal of information that can be used to identify priorities for improvement within the livestock inventory.

The error propagation method can also be applied to the Tier 2 equations for enteric fermentation and manure management. For manure management methane emissions, the 2019 Refinement to the 2006 IPCC Guidelines https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html (Vol. 1 Ch. 5, 3.1A) provides a worked example. For enteric fermentation, because the equations are complex, error propagation is usually done by applying some simplification. An example is given in Uncertainty Analysis of Agricultural CH_4 and N_2O emissions in Switzerland (Agroscope Reckenholz-Tänikon Research Station ART, 2008). The IPCC converts estimates of gross energy to methane emissions using IPCC (2006) Equation 10.21:

$$EF = \left[\frac{GE \times (\frac{Ym}{100}) \times 365}{55.65} \right]$$

Their approach was to estimate uncertainties for GE and Ym and then use error propagation to calculate overall emission factor uncertainty. Emission factor uncertainty can be further combined with activity data uncertainty using the error propagation rule. However, for many initial applications of a Tier 2 approach, the uncertainty of GE is not known. Furthermore, characterising the uncertainty of input variables used to estimate GE – including activity data uncertainty – is when uncertainty analysis becomes most useful for identifying priorities for improvement. Therefore, Monte Carlo simulation is a very useful method for uncertainty analysis. And because the IPCC Tier 2 equations for livestock use lots of activity data, it is useful for highlighting where improvements in activity data could bring the greatest benefits for reducing inventory uncertainty.

In brief, in Monte Carlo simulation, each input value in the IPCC enteric methane or manure management equations is characterised by a probability distribution. Monte Carlo simulation takes random values from within each distribution, and recalculates the equations using each randomly selected value. This is done thousands of times, resulting in a probability distribution for the output variable (e.g. total enteric fermentation emissions). With this distribution, the mean estimate is associated with a 95% confidence interval, and thus an uncertainty range relative to the mean. Some software packages also run correlations between the input and output variables. These correlations can be used to identify which variables have a stronger impact on the uncertainty of the output variable. Variables that use activity data and that have a stronger impact should be considered as potential priorities for improving inventory activity data inputs.

There are many different software packages that can run Monte Carlo simulation. For specific guidance on how to implement the analysis, refer to the specific manuals for the software being used. In general, however, when inputting data for Monte Carlo simulation, the common elements that must be input for each variable include the mean and the standard deviation, and a suitable probability density function (i.e. probability distribution of a particular shape) should be chosen. Of these, the mean is straightforward: input the value used in the inventory. Two common challenges faced are:

- How to choose what kind of probability density function to use? IPCC guidelines on uncertainty analysis provides guidance on selecting the appropriate probability density function. IPCC guidelines, together with recommendations based on existing uncertainty analysis for livestock Tier 2 applications, is summarized in **Methodological Focus D.2: Guidance on selecting PDFs for uncertainty analysis**. The 2019 Refinement to the 2006 IPCC Guidelines Vol. 1 Ch. 5 Section 3.6 also gives an example of the PDFs used for uncertainty analysis in Italy's inventory of enteric fermentation emissions.
- How to estimate the standard deviation when a parameter has been estimated using multiple data sources? When parameters are estimated using a single data source, the standard deviation around the mean can be calculated from the dataset or directly taken from the survey report. When parameters are estimated using multiple data sources, standard deviations can be combined using error propagation rules. A worked example is given in **Worked Example D.2: Combining standard deviations from multiple data sources**.

D.2 IPCC Guidelines and UNFCCC Decisions

IPCC definitions of quality control, quality assurance and verification

"**Quality Control (QC)** is a system of routine technical activities to assess and maintain the quality of the inventory as it is being compiled. It is performed by personnel compiling the inventory. The QC system is designed to: (i) Provide routine and consistent checks to ensure data integrity, correctness, and completeness; (ii) Identify and address errors and omissions; (iii) Document and archive inventory material and record all QC activities. QC activities include general methods such as accuracy checks on data acquisition and calculations, and the use of approved standardised procedures for emission and removal calculations, measurements, estimating uncertainties, archiving information and reporting. QC activities also include technical reviews of categories, activity data, emission factors, other estimation parameters, and methods.

Quality Assurance (QA) is a planned system of review procedures conducted by personnel not directly involved in the inventory compilation/development process. Reviews, preferably by independent third parties, are performed upon a completed inventory following the implementation of QC procedures. Reviews verify that measurable data quality objectives in the QA/QC Plan were met, ensure that the inventory represents the best possible estimates of emissions and removals given the current state of scientific knowledge and data availability, and support the effectiveness of the QC programme.

Verification refers to the collection of activities and procedures conducted during the planning and development, or after completion of an inventory that can help to establish its reliability for the intended applications of the inventory. For the purposes of this guidance, verification refers specifically to those methods that are external to the inventory and apply independent data, including comparisons with inventory estimates made by other bodies or through alternative methods. Verification activities may be constituents of both QA and QC, depending on the methods used and the stage at which independent information is used."

Source: 2006 IPCC Guidelines Vol. 1, Ch. 6.

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IPCC good practice in documentation of Tier 2 livestock emission estimates

The 2006 IPCC Guidelines (Vol. 4, Ch. 10) recommend that the following items are documented:

Activity data:

- Document all animal population data by sub-category; the sources of all activity data used in the calculations (e.g. statistical database references), or the assumptions used to develop activity data if these were not directly obtained from databases;
- Document population data collection methods; estimates of accuracy and precision; and potential areas of bias. Evaluate the representativeness of the data.

Emission factors:

- Document the values used for Y_m, DE and all data used, including their references;
- Document definitions of input parameters and how emission factors were derived;
- Describe sources and magnitudes of uncertainties;
- For manure management emissions, document climatic conditions (i.e., average temperature during manure storage); manure management system data by livestock sub-category and by region, if applicable; VS and Bo values for all livestock in inventory; and MCF values for all manure management systems used.

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IPCC good practice in QAQC and verification of Tier 2 livestock emission estimates

Specific good practices for QC, QA and verification of livestock emission sources recommended in the 2006 IPCC Guidelines (Vol. 4, Ch. 10) include:

- Check that livestock sub-category data were collected and aggregated correctly;
- Cross-check livestock population data with previous years to ensure a reasonable trend, and cross-check between FAO data and national agricultural statistics databases;
- Cross-check country-specific emission factors against the IPCC defaults, and explain any significant differences between country-specific factors and default factors;
- Conduct national and international expert review and document the review results;
- For manure management methane emissions, review the allocation of manure between manure management systems to determine if changes in the livestock industry or changes due to national agricultural policy and regulations are being captured; cross-check country specific values of VS excretion rates, B_o, and MCF against the IPCC defaults, and explain any significant differences with default parameters;
- For manure management N_2O emissions, compare country-specific values of $N_{ex}(T)$ and $MS_{(T,S)}$ with IPCC default values, and explain any differences;
- Compare implied N_2O emission factors and nitrogen excretion rates with alternative national data sources and with data from other countries with similar livestock practices.

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D.3 Useful tools

This section provides three tools to assist in inventory compilation:

Tool D.1: Suggested structure for Tier 2 livestock inventory report

Tool D.2 Searchable database of activity data underlying Tier 2 emission factors

Tool D.3 Checklist for general quality control activities

Tool D.1: Suggested structure for Tier 2 livestock inventory report

The suggested structure in this tool is based on the structure of the national inventory report outline for Annex 1 countries. For developing country inventories, the structure and contents may be adjusted as required.

1.1. Source category name and reporting category code (e.g. "3A1ai Methane emissions from dairy cattle")

See IPCC (2006) Volume 1 Chapter 8 Reporting Guidance and Tables for category codes

1.1.1. Source category description

Briefly describe which emission sources (e.g. enteric fermentation, manure management etc.), which gases (CH_4 or N_2O) from which animal types (cattle, sheep, goats etc.) are included in the estimates in this chapter. Which of these are key category sources in the inventory, and which are estimated using Tier 2 approaches. A brief description of the livestock sector in the country or a reference to a report on the livestock sector is also useful to provide context for readers.

1.1.2. Methodological issues

Describe in detail (or in summary with reference to annexes containing details) the method used (e.g. "IPCC Tier 2 equations for enteric fermentation emissions"). Present the animal population data used for each animal sub-category. Describe the methods, data sources and data values used to estimate net energy for maintenance, activity, growth, pregnancy, lactation and work; digestibility; the methane conversion factor used; and the resulting estimates of gross energy and/or emission factors. Describe any methodological issues relevant to allow a reader to understand how the emission estimates were derived.

1.1.3. Uncertainties and time-series consistency

Present the estimated uncertainty of activity data with explanation of how the estimate was derived.

Present the estimated uncertainty of emission factors, with explanation of how the estimates were derived.

Present the estimated combined uncertainty for the source.

Give an assessment of whether the reported Tier 2 time series is consistent.

1.1.4. Source-specific QA/QC and verification, if applicable

Describe the QAQC activities applied to this source, with description of any corrections made after QC and results of QA or verification (e.g. comparisons between estimated emission factors and IPCC defaults or other comparisons that were made).

1.1.5. Source-specific recalculations, if applicable

A comparison of the Tier 2 emissions time series with a previously submitted Tier 1 time series and (where applicable) comparison of the Tier 2 emissions time series with a Tier 1 estimate of the emissions time series using the animal population time series since the previous submission.

1.1.6. Source-specific planned improvements, if applicable

Summary of planned or prioritized future improvements to the Tier 2 inventory, including any planned or prioritized improvements in estimation methodologies, activity data or emission factors.

Suggested tables for reporting of the activity data underlying emission factor estimates

Table for reporting activity data sources for enteric fermentation (*illustrative contents are in italics*)

Parameters	Units	Data sources
Number of animals	Head	*XXX statistical yearbook*
Live weight	kg	*Expert judgement from animal breeding centre*
Coefficient for net energy for maintenance (Cf_i)	Fraction	IPCC Guidelines (cattle, Table 10.4, Vol. 4, pg. 10.16)
Daily weight gain	kg/day	*XXX report*
Mature weight	kg	*Expert judgement from animal breeding centre*
Coefficient for net energy for growth (C)	coefficient	*IPCC (2006) Vol. 4, Eq. 10.6, pg. 10.17*
Percent of cows pregnant	%	*Ministry of Agriculture expert judgement*
Coefficient for pregnancy (C_p)	Fraction	IPCC Guidelines (table 10.7, pg.10.20, vol.4)
Daily milk yield	kg/cow/day	*XXX statistical yearbook*
Fat content of milk	%	*IPCC (2006) pg. 10.60, default value*
Work	Hours/day	*Ministry of Agriculture expert judgement*
Digestible energy	%	*Multiple sources, see Annex 5*
Net energy for maintenance	MJ/day	*IPCC (2006) Eq.10.3 and Table 10.4*
Net energy for activity	MJ/day	*IPCC (2006) Eq.10.5 and Table 10.5*
Net energy for growth	MJ/day	*IPCC (2006) Eq.10.6*
Net energy for pregnancy	MJ/day	*IPCC (2006) Eq.10.13 and Table 10.7*
Net energy for lactation	MJ/day	*IPCC (2006) Eq.10.8*
Net energy for work	MJ/day	*IPCC (2006) Eq.10.11*
Ratio of net energy in a diet for maintenance to digestible energy consumed		*IPCC (2006) Eq.10.14*
Ratio of net energy available for growth in a diet to digestible energy consumed		*IPCC (2006) Eq.10.15*

Parameters	Units	Data sources
Gross energy intake	MJ/day	*IPCC (2006) Eq.10.16*
Methane conversion rate	%	*IPCC (2006) Table 10.12*
Methane emission factor	Kg CH_4/ head/year	*IPCC (2006) Eq. 10.21*

Suggested table for reporting activity data values used for enteric fermentation (cattle)

Year	Live weight (kg head^{-1})	Daily weight gain (kg head^{-1} day^{-1})	Mature weight (kg head^{-1})	Milk yield (kg head-1 day^{-1})	Fat content of milk (%)	Cows giving birth in the year (%)	Feed digestibility (%)	Work (hours head^{-1} day^{-1})

Suggested table for reporting activity data values used for enteric fermentation (sheep, goats)

	Sheep sub-category 1	*Sheep sub-category 2*	*Sheep sub-category 3*
Days alive (days/year)			
W (kg)			
Cf_i			
C_a			
WG (kg/day)			
Wool (kg/year)			
Milk production (kg/day)			
Energy value of milk (MJ/day)			
$C_{pregnancy}$			
Feed digestibility (%)			

Suggested tables for reporting activity data values used for manure management

Suggested table for reporting parameters used in estimating volatile solids and EF per head

	DE (%)	Ash (%)	Bo (m^3/kg VS)	VS (kg VS/day)
Sub-category 1				
Sub-category 2				
Sub-category 3				
Sub-category 4				

Suggested table for reporting share of each manure management systems (%)

	Liquid storage	Solid storage	Dry lot	Daily spread	[etc.]
Sub-category 1	*35.0*	*25.0*	*15.0*	*25.0*	*0.0*
Sub-category 2	*25.0*	*35.0*	*15.0*	*10.0*	*15.0*
Sub-category 3	*etc.*				
Sub-category 4					

Suggested table for reporting parameters used in estimating nitrogen excretion and N2O emissions per head

	%CP in diet	Fat content in milk (%)	Protein content in milk (%)	Weight gain per day (kg day^{-1})	Nex (kg N head^{-1} day^{-1})
Sub-category 1					
Sub-category 2					
Sub-category 3					
Sub-category 4					

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Tool D.2 Searchable database of activity data underlying Tier 2 emission factors

Tool D.2 is a web-based interactive tool that can be used to check activity data provided by the user on animal characteristics, performance and management and the resulting emission factors against a database of the activity data used to develop IPCC Tier 1 default emission factors for enteric methane, as well as the activity data used in a large number of enteric methane emission factors developed using a Tier 2 approach and submitted by Parties to the UNFCCC. The database only includes activity data and emission factors for dairy and other cattle. The user interface can be accessed here: https://www.agmrv.org/bovine/

Users select the type of cattle they wish to compare their input data with, and input their own data values for animal performance or management, and the application identifies the most similar entries in the database. The user can then download these entries and compare their estimated activity data and emission factor values with the similar entries in the database. All the database entries either derived from IPCC default values given in IPCC (2006) Vol. 4 Ch.10 Annex 10A.1, from national inventory reports or national communications or biennial update reports submitted to the UNFCCC. Users are therefore encouraged to consult the original data sources to further understand similarities and differences between their own country's context and the livestock systems described in the database. This comparison can support verification of activity data and emission factors developed using country-specific information.

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Tool D.3 Checklist for general quality control activities

Data collection and input	
Have the assumptions for selection of activity data been transparently documented?	▪ Check that the description of activity data and justification for choice of activity data are properly recorded ▪ Check that bibliographical references are properly cited in the inventory report
Are the activity data values selected reasonable?	▪ Check that the value for each parameter has been compared with the values reported in other data sources
Have the appropriate default values been used?	▪ If any IPCC default values were used, does the inventory report justify the appropriateness of the value chosen?
Are the datasets used to estimate activity data good quality?	▪ Check if QC procedures were applied to any of the datasets used in inventory compilation. If so, document them. ▪ Check the data quality scoring applied to each data source in inventory compilation using Tool B.16.
Were there any errors in data transcription or data entry?	▪ Check a sample of input data for transcription errors. ▪ Check that spreadsheets use methods to minimize data entry errors: • Avoid hardwiring factors into formulas. • Create automatic look-up tables for common values used throughout calculations. • Use cell protection so fixed data cannot accidentally be changed. • Build in automated checks, such as computational checks for calculations, or range checks for input data.
Where activity data parameters have been calculated from other indicators or where gap-filling methods have been used, have calculations been correctly implemented?	▪ Reproduce a sample of calculations. ▪ Compare calculation results with calculations made using alternative methods
Are parameter units correctly recorded and were appropriate conversion factors used?	▪ Check that all activity data units are properly labelled in the spreadsheets and inventory report ▪ Check that units are correctly carried through from beginning to end of calculations. ▪ Check that conversion factors are correct.

Are data used in different parameters or categories are consistent?	▪ Identify parameters that were estimated using common indicator variables and check that the values used are consistent ▪ Identify livestock sub-categories and emission categories (e.g. enteric fermentation, methane manure management) that use the same input data and check that the values used are consistent
Calculation checks	
Have livestock sub-populations between correctly aggregated?	▪ Check that data on different animal sub-categories have been correctly aggregated
Have activity data time series been estimated using consistent methods?	▪ Check a sample of parameter time series for consistency, e.g. if there is sudden divergence from the trend (e.g. >10% jump between years), check for data input or calculation errors ▪ Check if there any unusual or unexplained trends in activity data across the time series.
Have all the required parameters for all relevant animal sub-categories been estimated?	▪ Check that all the required parameters for each animal sub-category have been estimated. ▪ If any parameters or sub-categories have not been completely estimated, check that this has been transparently documented
Data Documentation	
Has the inventory been clearly documented?	▪ Check that definitions and units have been documented for each input parameter. ▪ Check that the inventory data and methods have been clearly documented to enable a reader to replicate the calculations. ▪ Check that the source of each activity data has been clearly documented

*Source: Adapted from US EPA "*Template 3: Description of QA/QC Procedures*"*

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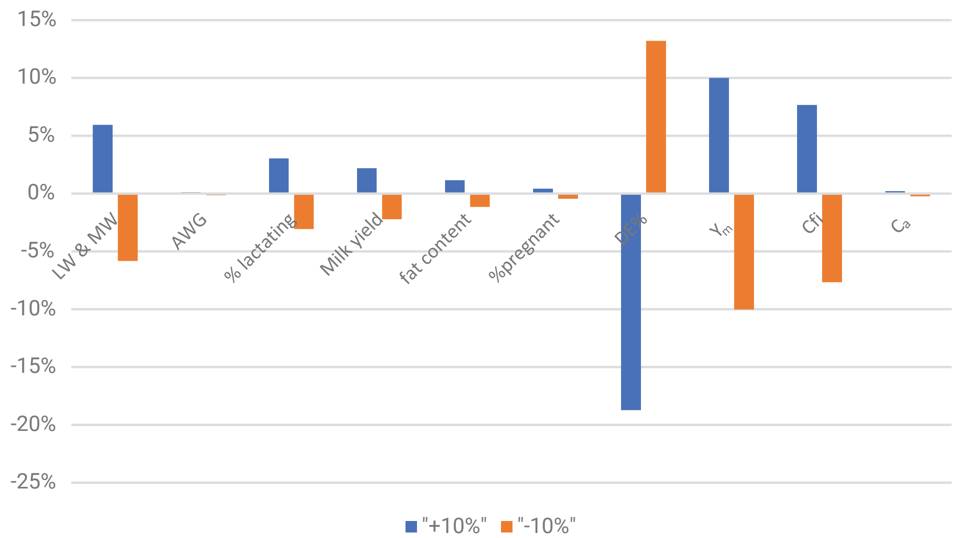
D.4 Methodological guidance

Methodological Focus D.1: Difference between sensitivity analysis and uncertainty analysis

Sensitivity analysis is a rapid method for assessing which input variables have a significant impact on an output variable (e.g. an emission factor). A very simple method to implement sensitivity analysis of emission factors is to list all the input variables used in calculating an emission factor, and to vary each variable in turn first by +10% and then by -10%. The resulting percentage change in the emission factor is recorded and used to identify which input variables have the greatest effect on the estimated emission factor.

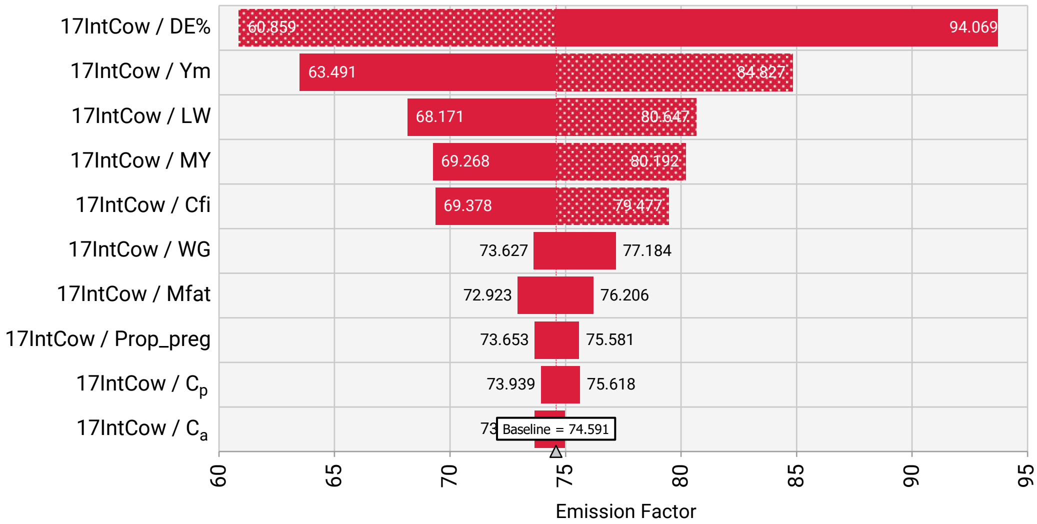
When Kenya began to elaborate its dairy cattle GHG inventory, this method of sensitivity analysis was applied to an initial draft of the inventory to identify which variables should receive the most attention in terms of literature review and analysis. The results of that preliminary assessment are shown in **Figure 20**. The figure shows that the digestibility of feed, the methane conversion factor, the coefficient for maintenance and live weight had significant impacts on the emission factor. A 10% change in the other input variables led to less than 5% change in the estimated emission factor.

Figure 20: Sensitivity analysis of the emission factor for dairy cows in Kenya



After compiling the inventory, formal uncertainty analysis was applied using the Monte Carlo approach. **Figure 21** ranks the input variables by the value of the correlation coefficient between each variable and uncertainty of the emission factor. The main results are broadly similar to the results of sensitivity analysis, because feed digestibility, the methane conversion factor, live weight and the coefficient of maintenance are all identified as significant variables. However, their rank order differs, and uncertainty analysis also identified milk yield as an important input variable.

Figure 21: Effect of input variable uncertainty on mean value of the emission factor for dairy cows in Kenya



The reason why the two methods produce different results is because sensitivity analysis only assesses the influence of the mean value of each input variable on the mean value of the output variable, while the Monte Carlo method assesses both the influence of each input variable and the effect of uncertainty in the estimate of the mean value for each input variable. For example, if two input variables have the same effect on the emission factor but their mean values are estimated with different margins of error, only uncertainty analysis will indicate a difference in their effect on the emission factor.

Based on this comparison, it is suggested that sensitivity analysis can be applied early in the initial inventory compilation process as a guide to how to allocate resources in the compilation process. Further inventory improvement can be guided by the results of the more formal uncertainty analysis completed after initial inventory compilation, when data sources have been selected and data to describe the uncertainty of estimated values used have been documented.

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Methodological Focus D.2: Guidance on selecting PDFs for uncertainty analysis

In Monte Carlo simulation, inputs are treated as random variables that are described by a probability density function (PDF). The mean of the PDF is the expected value of the input variable and the variance reflects the uncertainty. Not all variables will have a normal distribution, so the 2006 IPCC Guidelines (Vol. 1 Ch. 3) provides specific guidance on the selection of PDFs when using the Monte Carlo approach. The key points can be summarized as:

- The normal distribution may be appropriate when the range of uncertainty is small and symmetric to the mean. A small uncertainty range is when the standard deviation of the normal distribution does not exceed 30 percent of the mean value;

- A lognormal distribution may be appropriate when a variable can only have positive values, the variable is positively skewed and uncertainties are large;
- A triangular distribution may be appropriate where experts can provide estimates of upper and lower limits and a preferred value, but no other information about the distribution is available.

If empirical data is available, the shape of the distribution can be determined using the empirical dataset. Here, it is important to determine whether the dataset was obtained using a randomly selected representative sample. Literature reports may also indicate the shape of the distribution, or may be used to estimate the relative range of uncertainty. The default uncertainty ranges reported in the IPCC Guidelines also give some indication of whether the uncertainty range can be expected to be symmetrical to the mean (e.g. when uncertainty is reported as “±30%”) or asymmetrical (e.g. “uncertainty range of 2-24” around a mean of 8). In addition, some variables in the IPCC equations (e.g. coefficients) can only take a value between 0 and 1. If the uncertainty is small relative to the mean, they can be described by a normal distribution, but if the uncertainty is large, a different distribution (e.g. a beta distribution) is required to prevent negative values occurring. Examples of why certain PDFs were selected for use in uncertainty analysis of livestock emissions can be found in papers analysing uncertainty in inventories of Finland https://link.springer.com/article/10.1007/s11027-006-4584-4, the UK, https://www.sciencedirect.com/science/article/pii/S1352231013007656, and Canada https://www.cambridge.org/core/journals/journal-of-agricultural-science/article/sources-of-uncertainty-in-the-ipcc-tier-2-canadian-livestock-model/A63B8DA630CEA64C90C15FCC187DCAD1

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D.5 Worked examples

Worked Example D.1 Estimating uncertainty using error propagation

The most common method used by countries to calculate uncertainty of Tier 2 livestock emission estimates uses a country-specific estimate of livestock population data uncertainty and the IPCC default estimates of uncertainty for Tier 2 emission factors, which are combined using error propagation.

For example, Estonia's 2019 National Inventory Report estimates an uncertainty of ±0.72% for dairy cattle population data, and ±1.11% for the non-dairy cattle population. The source of this estimate is Statistics Estonia, which follows the European Union regulations on livestock statistics and produces an estimate of the uncertainty of livestock population data. Both dairy and non-dairy cattle were estimated using the Tier 2 approach. IPCC (2006) Vol. 4 Ch. 10 page 33 estimates that the uncertainty of Tier 2 emission factors is likely to be in the order of ±20%.

Following the error propagation rules given in IPCC (2006) Vol. 1 Ch. 3 page 28:

$$U_{total} = \sqrt{U_{AD}^2 + U_{EF}^2} = \sqrt{0.72^2 + 20^2} = 20.01\%$$

The uncertainty of dairy cattle emissions in the inventory is estimated as ±20.01%, and using the same equation non-dairy cattle uncertainty is estimated at ±20.03%.

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Worked Example D.2: Combining standard deviations from multiple data sources

When multiple data sources are used to estimate a mean value in the inventory, error propagation rules can be used to combine standard deviations from each source and provide an estimate of the standard deviation of the resulting combined mean. The combined standard deviation of two sample estimates, i and j, can be calculated as:

$$SD_{combined} = \sqrt{\frac{SD_i^2}{n_i} + \frac{SD_j^2}{n_j}}$$

For example, country A does not have nationally representative data on live weight for ewes, so it used survey results reported in the literature. Three studies with different sample sizes reported the live weight of ewes and their standard deviations as shown in **Table 19**. The sample-weighted mean can be calculated as 46.45 kg, and applying the equation above gives a combined standard deviation of 2.83 kg:

$$\sqrt{\frac{44.6^2}{44} + \frac{48.1^2}{72} + \frac{46.0^2}{83}} = 2.83$$

Table 19: Hypothetical data to illustrate calculation of combined standard deviation

	Sample size	Sample mean (kg)	Sample s.d. (kg)
Sample *i*	44	44.6	12
Sample *j*	72	48.1	14
Sample *k*	83	46.0	13

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D.6 Additional resources

IPCC Guidance

IPCC (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

IPCC (2006) Vol. 1 Ch. 3 Uncertainties

IPCC (2006) Vol. 1 Ch. 6 Quality assurance/quality control and verification

IPCC (2006) Vol. 4 Ch. 10 Emissions from Livestock and Manure Management.

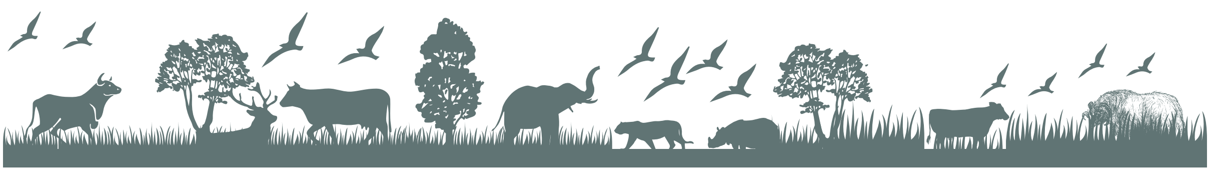
IPCC (2019) 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Other materials

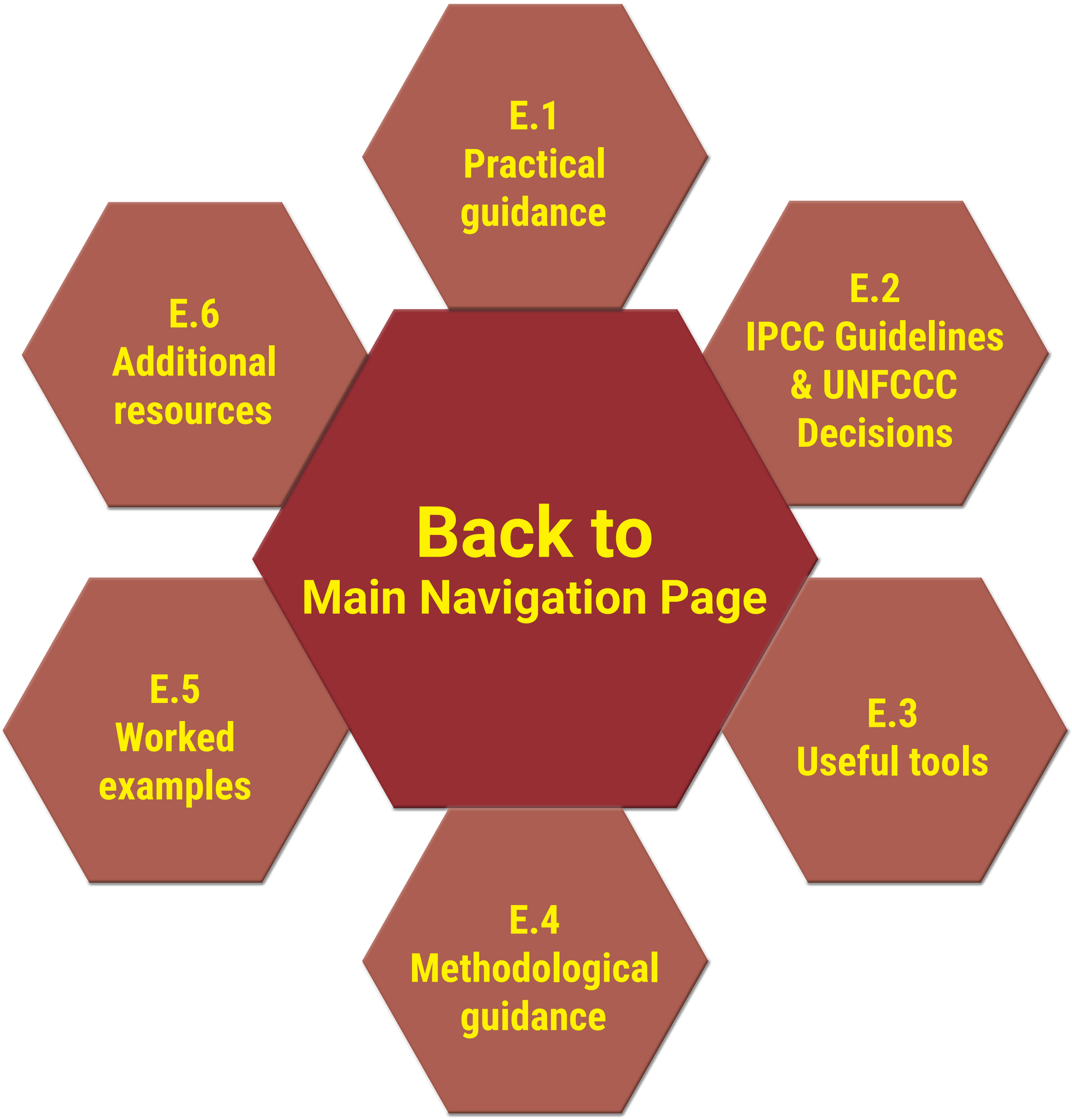
CGE Training materials for the preparation of national communications from non-Annex 1 Parties contains training modules on quality assurance/quality control and verification and uncertainty analysis

The US Environmental Protection Agency has produced capacity building materials that include templates for documenting methods and data, quality assurance and quality control activities and archiving systems.

The GHG Protocol has produced accessible materials on uncertainty assessment



E. Continuous improvement



There are few countries where all the necessary livestock activity data are readily available and of good quality for use in an initial Tier 2 approach livestock GHG inventory. Moreover, given resource limitations for inventory compilation, there will always be trade-offs between the inventory quality objectives of timeliness, transparency, accuracy, consistency, completeness and comparability. The IPCC (2006) Guidelines (Vol. 1 Ch. 1) note that following IPCC good practice can not only help meet inventory quality objectives but also help maintain inventories "in a manner that improves inventory quality over time". Continuous improvement to support improved reporting and transparency is also explicitly encouraged in the Annex to the Modalities, Procedures and Guidelines on transparency of the Paris Agreement (paragraph 7). See **IPCC good practice guidance on continuous improvement and UNFCCC decisions on continuous improvement**.

Continuous improvement of national GHG inventories involves several aspects, including key category analysis, methodological improvements, institutional arrangements that support inventory improvement, staff hiring and training, and better data quality. Issues relating to all these aspects can be captured using the process recommended for preparing inventory improvement plans in Developing a National Greenhouse Gas Inventory System published by US EPA, which is summarized in **Tool E.1 Process for compiling an inventory improvement plan**. For livestock GHG inventories specifically, all these aspects may be relevant and further guidance can be found in Section **E.6 Additional resources**. This section of the L-ADG guidelines focuses on improvements in activity data.

Once a Tier 2 inventory has been compiled, important sources of information to inform decisions on inventory improvement include the results of QA/QC and verification, data quality assessment and uncertainty analysis. These sources of information are discussed in Section **E.1.1 Identifying areas for improvement.** In many countries, the availability and quality of livestock statistics is unable to meet stakeholders' needs. Longer-term options for improving data availability and quality through improvements in livestock statistics are discussed in Section **E.1.2 Improvements in national livestock statistics**. Consideration of both of these aspects should lead to identification of planned activities in an inventory improvement plan.

E.1 Practical guidance

E.1.1 Identifying areas for improvement

Three important sources of information on data and inventory quality are:
- Documentation of QA/QC and verification activities;
- Data quality assessment results; and
- Uncertainty analysis.

While uncertainty analysis is often seen as the main tool to identify areas for improvement, uncertainty analysis relates mainly to the accuracy of the data used, and may have little to say about transparency, completeness or other quality aspects. Furthermore, when the underlying data are statistically robust but poorly representative, quantitative estimates of uncertainty may be centred around an inaccurate estimate of the mean value of input parameters. Therefore, it is recommended to draw on all three of the above information sources as inputs into developing an inventory improvement plan (see **E.1.3 Developing an inventory improvement plan**).

Improvements based on QA/QC and verification activities

QA/QC and verification activities were discussed in Section **D.1.2 QA/QC and verification**. QC activities involve checks to identify errors and to ensure transparency, completeness, accuracy and other quality objectives are met. QA activities involve reviews by people not involved in inventory compilation and audits to ensure that QC activities have been properly conducted and documented. Documentation of both QC and QA activities can assist in identifying two types of quality issues relevant to continuous improvement:
- Quality issues that could not be addressed during compilation of the last inventory; and
- Quality issues that were addressed, but for which further improvements in working methods or procedures are needed.

External reviews, either informal or formally conducted as part of the UNFCCC process, are also an important source of information on potential improvements.

Improvements based on data quality assessment

Section **B.1.1 General guidance** on data quality assessment recommended to use a spreadsheet template to document the data sources used in inventory compilation and score each data source against eight criteria for data quality. This can be accomplished using **Tool B.16: Template for data quality assessment spreadsheet**. Each worksheet in the tool records for each parameter the quality scores as well as inventory compilers' comments justifying the scores given and/or noting possible quality issues for each data source. The summary worksheet gives a visual overview of which parameters were scored higher or lower based on the quality of data sources used, and allows users to compare the scores given for each data quality criterion. An example of how this was used to identify improvement options in Kenya's dairy cattle GHG inventory is given in **Worked Example E.1 Application of data quality analysis**. The resulting improvement options may include activities that can improve data sources in terms of transparency, accuracy, completeness and consistency as well as data accessibility and timeliness.

Improvements based on uncertainty analysis

Uncertainty analysis not only provides a quantitative estimate of the uncertainty of estimated emissions but also helps identify parameters that have the greatest contribution to uncertainty. Because total emissions in any category are the product of activity data and emission factors, uncertainty analysis should focus both on population data and other activity data that have a large influence on estimated emissions. An example is given in **Worked Example E.2 Identifying improvement options for uncertainty analysis of Kenya's dairy cattle inventory**. In that example, improvements in population data were identified as having a significant potential to improve inventory quality and reduce inventory uncertainty. Because of the limited availability and/or poor quality of livestock statistics in many countries, it is likely that in many countries improvements in population data are as relevant as improvements in the data underlying Tier 2 emission factors.

E.1.2 Improvements in national livestock statistics

Improvements in national livestock statistics are relevant to improve the availability and quality of activity data used in the Tier 2 approach. Improvements in national livestock statistics should target one of the identified quality dimensions, i.e. transparency, completeness, consistency, accuracy, accessibility or timeliness. For some dimensions, such as transparency and accessibility, improvements can be straightforward as they might involve, for example, improved description of the data sources or improved ways to disseminate and make the data available to inventory compilers. For other quality dimensions, improvements are more challenging because data on livestock are typically collected as part of broader statistical operations, for which any modifications should be discussed with a variety of stakeholders, each with different interests. These improvements could, for example, involve: (i) reformulation of some questions in statistical surveys, so as to get more accurate responses from the sampled households or farms; (ii) inclusion of additional questions in statistical surveys; (iii) training for extension officers in charge of collecting administrative data at local level; (iv) changes to sampling methods to ensure the generated datasets better capture the required livestock inventory data; (iv) changes to methods of data processing and dissemination to improve data timeliness.

Many countries already have a formal process through which statistical agencies engage other ministries and stakeholders to review and improve statistical data collection procedures. However, while identifying options to fill gaps in the national statistical systems is relatively straightforward, the most challenging part is to agree upon the necessary actions and investments to fill the gaps and ensure they are implemented. Therefore, one should keep in mind the following issues:

- In all countries, national livestock statistics on their own cannot provide all the data necessary to estimate GHG emissions from livestock using a Tier 2 approach. The tools presented in Section **B.3 Useful tools** clearly highlight that national statistics are appropriate to estimate only some livestock activity data and parameters. This implies that any effort to improve national livestock statics should be complemented with parallel actions to fill other data gaps, if required.

- Many countries have a Plan for Statistical Development in place, which provides both a vision for the future of the national statistical system and details priority areas of investments for improving data availability and quality. Investments to improve national livestock statistics should be consistent with this broader framework, which ensures high-level support and also supports the sustainability of good quality livestock data in the medium to long-term.
- National statistics are gathered through different instruments and any proposed improvement should target a specific data collection instrument. The agricultural census, agricultural surveys and administrative records, for example, represent different tools that a country can use to generate data on livestock. How data from each tool are disseminated and made available to the public differs. Any effort to improve national livestock statistics, therefore, should target specific data collection tools, which should be well understood by inventory compilers.
- Any improvement in the national statistical system is effective at improving the generation of accurate activity data in the medium to long-term. National statistics are generated on a regular basis, sometimes annually, sometimes every other year, or even every ten years as with the agricultural census. In addition, there is a time lag between making improvements in the data collection instrument and the time when data becomes available to inventory compilers. One should not expect, therefore, that improvements in the national statistical system will immediately result in good quality inventory data, but consider these improvements as a major tool for obtaining good quality data on a regular basis in future years.
- Any improvement in the national statistical system involves costs and, typically, resources are limited. It is always wise, therefore, to propose multiple changes to improve the statistical systems that, in aggregate, result in minor or no change in the budget necessary to collect, process and properly disseminate data. This can be done by looking beyond the necessary livestock activity data to more broadly consider the entire demand for livestock data from national stakeholders. By creating a "coalition for change" for improving the national livestock statistical system, the chances of improving the quantity and quality of livestock activity data will significantly improve in the medium to long-term.

E.1.3 Developing an inventory improvement plan

Options for improvements in the quantity and quality of activity data and activity data compilation activities can be summarized in a long-list of improvement options. **Table 20** shows a suggested format for recording the identified issues and improvement options.

Table 20: Suggested format for recording activity data issues and improvement options

Inventory year:	2018		
Source category:	Enteric fermentation		
Animal sub-category	**Parameter estimated**	**Describe problem**	**Potential improvement**
Dairy cow, Western region	*Live weight (2018)*	*Extrapolated from time series*	*Live weight measurement survey*
All sub-categories, Eastern region	*Population (2018)*	*Estimated using expert judgement*	*Use results of 2019 census*
…	…	…	…

Table 21: Suggested format for recording prioritization of improvement options

Prioritization level	Improvement option
Medium	*Live weight measurement survey for dairy cows in Western Region*
High	*Ensure access to 2019 census results for Eastern Region by signing MoU with census agency.*

Some data quality issues and improvement options will be obvious from the three sources of information discussed in Section **E.1.1 Identifying areas for improvement**. However, issues arising due to institutional issues (e.g. coordination between agencies) or working procedures (e.g. how data is managed or archived) may not be apparent from these sources. Therefore, it is advisable to discuss data quality issues and improvement options with those involved in data supply and inventory compilation. Since continual improvement is a key function of inventory compilation, it may also be useful to establish working groups or advisory panels specifically tasked with supporting continual improvement. An example is given by the Agricultural Inventory Advisory Panel established by the Ministry of Primary Industries in New Zealand. **Tool E.1 Process for compiling an inventory improvement plan** sets out a process that can help to ensure that data quality improvements are captured together with other inventory-related improvements in an inventory improvement plan.

Once improvement options have been synthesized, they can then be prioritized. The 2006 IPCC Guidelines (Vol. 1 Ch. 4) recommends that inventory improvements are targeted to key categories and major sub-categories within those key categories (see **Methodological Focus E.1: Continuous improvement and key category analysis**). However, once key categories or major sub-categories have been identified, there are likely to be many parameters requiring improved data. A simple way to prioritize among these options is to rank improvement options as ‘high’, ‘medium’ or ‘low’, which can be documented in a format such as that shown in **Table 21**. Prioritization may be done on the basis of the contribution of each improvement to quality of the national inventory. It may also consider other factors, such as the anticipated costs and the potential contribution to national livestock sector policies. Drafting budgets for high priority improvements can provide an indication of the resources required to implement priority improvements, including through differentiating between investment costs and the recurrent costs required to regularly collect good quality inventory data.

Financial, time and other constraints mean that it will inevitably be impossible to implement all the identified improvement options. National agencies responsible for compiling GHG inventories will consider livestock inventory improvements alongside improvements in other sectors and overall inventory activities such as key category analysis, which is not conducted at the category level. Therefore, improvements that are prioritized for the livestock inventory may not be prioritized for the inventory overall. Much of the data required for Tier 2 livestock inventories is also important for informing national livestock development policies. Therefore, it may be useful to elaborate inventory improvement plans together with key stakeholders in the livestock sector. Implementation of improvement priorities can also be discussed with agencies and initiatives in the sector, since data improvements will benefit not only the inventory but also help meet other stakeholders' with information needs. In many countries or regions there are already livestock stakeholder platforms and for a that facilitate dialogue on livestock development issues, including data and statistics. Examples include national livestock policy hubs in Ethiopia and Uganda; the Eastern Africa Regional Animal Health Network; the One Health South Asia Network; Asia and Pacific Commission on Agricultural Statistics and the Livestock Data for Decisions community of practice. Linking with such national and regional networks and hubs is an effective way to support wide and transformative changes in the quantity and quality of livestock inventory data.

E.2 IPCC Guidelines and UNFCCC Decisions

IPCC good practice guidance on continuous improvement and UNFCCC decisions on continuous improvement

Continuous improvement is recognized in the 2006 IPCC Guidelines (Vol. 1 Ch. 2) as a good practice in data collection, where the following guidance is given:

- "Focus on the collection of data needed to improve estimates of key categories which are the largest, have the greatest potential to change, or have the greatest uncertainty.
- Choose data collection procedures that iteratively improve the quality of the inventory in line with the data quality objectives.
- Put in place data collection activities (resource prioritisation, planning, implementation, documentation etc.) that lead to continuous improvement of the data sets used in the inventory.
- Collect data/information at a level of detail appropriate to the method used.
- Review data collection activities and methodological needs on a regular basis, to guide progressive, and efficient, inventory improvement.
- Introduce agreements with data suppliers to support consistent and continuing information flows."

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UNFCCC decisions on continuous improvement

Continuous improvement to support improved reporting and transparency is also explicitly recognized as a guiding principle in the Annex to the Modalities, Procedures and Guidelines on transparency of the Paris Agreement (paragraph 3b). Paragraph 7 also states that Parties should report areas of improvement in their biennial transparency report, including ongoing and planned improvement activities.

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E.3 Useful tools

Tool E.1 Process for compiling an inventory improvement plan

Developing a National Greenhouse Gas Inventory System, published by US EPA, sets out a systematic process for developing an inventory improvement plan that captures a variety of issues alongside data quality issues. The EPA's approach is based on a series of templates for documenting **institutional arrangements, methods and data** used, **QA/QC procedures**, the **archiving** system and **key category analysis**. The last section of each template documents potential improvements that can be made. These improvements are brought together in an inventory improvement plan that can be completed in 10 steps:

STEP 1: Set out country-specific objectives for the improvement plan

STEP 2: Summarize priorities for improving institutional arrangements

STEP 3: Summarize findings from the key category analysis template

STEP 4: Summarize improvements identified in the methods and data documentation

STEP 5: Summarize potential QA/QC improvements

STEP 6: Summarize potential archiving improvements

STEP 7: Describe communication, outreach, and training activities/plans

STEP 8: Summarize potential improvements across all templates

STEP 9: Prioritize inventory improvements

STEP 10: Propose inventory improvement projects

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E.4 Methodological guidance

Methodological Focus E.1: Continuous improvement and key category analysis

IPCC (2006) Vol. 1 Ch. 4 defines a key category as "one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of greenhouse gases in terms of the absolute level, the trend, or the uncertainty in emissions and removals". Two approaches are described for identifying key categories. In brief, Approach 1 involves compiling the emissions from each emission category, summing them in descending order of magnitude and identifying all the categories that add up to 95% of the total level of emissions in the inventory. Approach 2 is similar, but assesses the contribution of each category to total uncertainty of the inventory estimate.

At what level of disaggregation should key category analysis be conducted? Table 4.1 in that chapter lists enteric fermentation (3A1) and manure management (3A2) as suggested categories to apply Approach 1. However, the IPCC Guidelines also note that inventory compilers should determine if particular sub-categories of emissions are significant. It suggests that "those subcategories that contribute together more than 60 percent to the key category should be treated as particularly significant. It may be appropriate to focus efforts towards methodological improvements of these most significant subcategories." In addition, disaggregating livestock types by sub-categories can help identify whether there are particular livestock sub-categories that should be a focus for future improvements.

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E.5 Worked examples

Worked Example E.1 Application of data quality analysis

Tool B.16: **Template for data quality assessment spreadsheet** was applied to all the data sources used in compiling Kenya's Tier 2 inventory for dairy cattle. That inventory reported emission estimates for 5 sub-categories of dairy cattle in 3 different production systems. Data availability and the quality of available data varied between production systems and animal sub-categories. Figure 22 shows a snapshot of the resulting data quality summary. The colour coding visually shows which parameters used datasets that were scored higher or lower against which quality assessment criteria. For example, although data for the intensive production system was abundant, the average score for transparency of data sources in the intensive system was low because many parameters were estimated using an unpublished dataset. A direct implication is that transparency of the inventory would improve if the data suppliers were to publish that dataset. Accuracy was lowest in the extensive production system because there was little available data on that production system and parameter values were often estimated using data from the semi-intensive production system. Future surveys conducted in the extensive production system could improve accuracy. The analysis also highlighted other data quality issues, such as lack of accurate estimates for the proportion of heifers that are pregnant in the semi-intensive production system.

Figure 22: Summary table showing data quality scoring for Kenya's dairy cattle inventory

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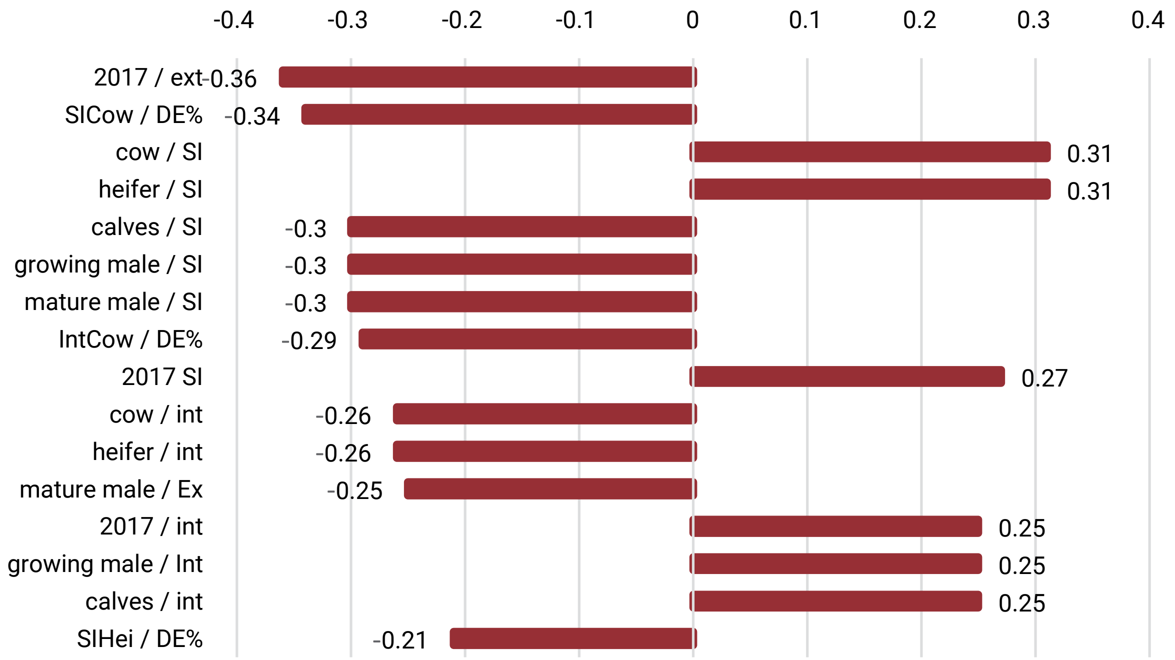
Worked Example E.2 Identifying improvement options for uncertainty analysis of Kenya's dairy cattle inventory

In compiling Kenya's Tier 2 dairy cattle GHG inventory, Monte Carlo uncertainty analysis was applied separately to each livestock GHG source. It was then applied to all dairy cattle emission sources together by converting methane and nitrous oxide to CO_2 equivalents using the AR4 GWPs (methane = 25, nitrous oxide = 298). The main factors correlated with uncertainty of 2017 emissions were activity data (i.e. proportion of total national herd in different production systems, proportions of each sub-category in the herd in each production system), and feed digestibility for cows and heifers (Figure 23).

Figure 23: Correlation coefficients between total 2017 CO_2e emissions from all dairy cattle sources and input variables in Kenya's GHG inventory



In particular, the factor with the biggest impact on total dairy emissions was the proportion of cattle in the extensive system, which had been estimated using expert judgement. Herd structure in the semi-intensive system – which accounted for more than 50% of total emissions – was also a significant driver of uncertainty. Feed digestibility for cows in the semi-intensive and intensive production systems and for heifers in the semi-intensive production system were also important factors.

To illustrate the effects of obtaining improved activity data and reducing input value uncertainty, a simulation was carried out in which the uncertainty range of the allocation of cattle to the three production systems and herd structure in each production system was halved. As a result, the uncertainty of total 2017 dairy cattle emissions would reduce from 18.2% to 16.2%.

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E.6 Additional resources

On sustainable inventory processes

The UNFCCC has produced several materials to support MRV in non-Annex 1 countries, which are available at https://unfccc.int/process-and-meetings/transparency-and-reporting/support-for-developing-countries/guidelines-and-manuals-for-the-preparation-of-non-annex-i-national-reports-and-international

The CGE has also produced training materials, including materials on GHG inventory compilation: https://unfccc.int/process-and-meetings/bodies/constituted-bodies/consultative-group-of-experts/cge-training-materials/cge-training-materials-for-the-preparation-of-national-communications

UNDP (2005) Managing the National Greenhouse Gas Inventory Process

Templates for inventory compilation

The US EPA template for national inventory improvement plans can be downloaded from http://ledsgp.org/wp-content/uploads/2017/06/template-6-national-inventory_improvement-plan.docx

Other templates for documenting a GHG inventory system can be downloaded from http://ledsgp.org/resource/greenhouse-gas-inventory-system/?loclang=en_gb

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