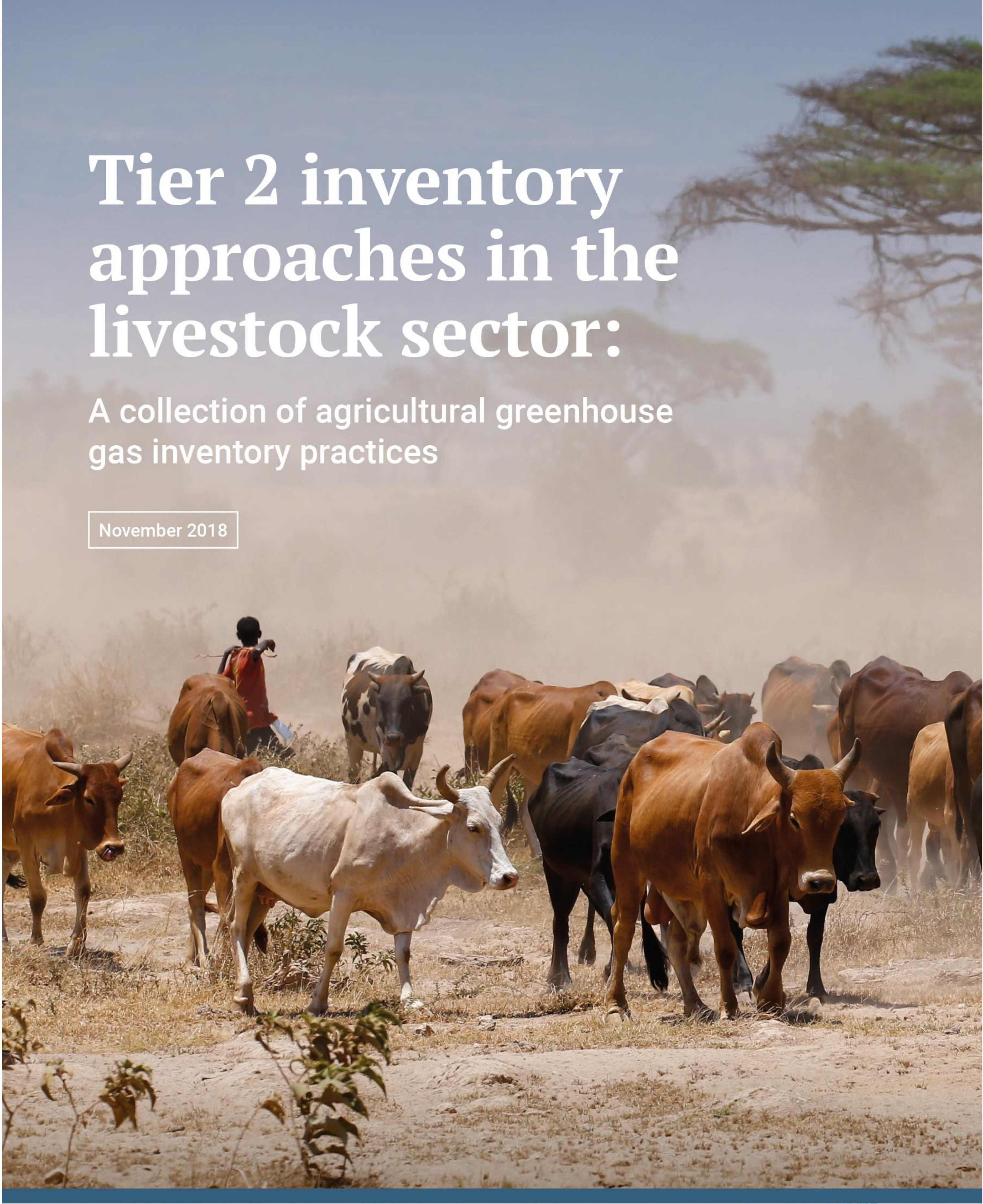

Tier 2 inventory approaches in the livestock sector:

A collection of agricultural greenhouse gas inventory practices

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CGIAR
RESEARCH PROGRAM ON Climate Change, Agriculture and Food Security
CCAFS

UNIQUE forestry and land use

GLOBAL RESEARCH ALLIANCE ON AGRICULTURAL GREENHOUSE GASES

Tier 2 inventory approaches in the livestock sector: a collection of agricultural greenhouse gas inventory practices

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The authors' views expressed in this document do not necessarily reflect the official opinions of these organizations, partner organizations, or countries.

ABOUT THE LIVESTOCK TIER 2 INVENTORY PRACTICES COLLECTION

This is a collection of information and examples describing how countries have used different data sources, methods, approaches and institutional processes to adopt and continually improve a Tier 2 approach for estimating livestock GHG emissions in national GHG inventories. The collection provides numerous case studies of how different countries have applied Tier 2 approaches in the livestock sector. These case studies are intended to inform about the practical methods countries use to compile their livestock GHG inventories and to stimulate those involved in livestock GHG inventories to devise methods for improved inventories that are suited to their national context. The collection also provides links to more formal guidance from the IPCC and other sources.

The collection is based on a review of GHG inventory submissions by 63 countries that currently (2017) use a Tier 2 approach. Enteric fermentation is the largest livestock emission source, and most countries have applied a Tier 2 approach to cattle. The collection therefore focuses on the use of Tier 2 approaches in estimating enteric fermentation emissions from cattle, although links with estimation of cattle manure management methane emissions are also discussed.

The collection is available as a stand-alone PDF document. Topic overviews and case studies are also available on the navigable web portal, **MRV Platform for Agriculture** (www.agmrv.org) to which new case studies and links can be added. The collection is structured around six topics:

1. Understanding Tier 2 approaches for livestock emissions: the benefits of using Tier 2 approaches and an overview of how countries use them
2. Planning for Tier 2 livestock inventories
3. Data collection and compilation of Tier 2 livestock inventories
4. Implementing QA/QC procedures
5. Assessing uncertainty in a Tier 2 inventory
6. Continual improvement of Tier 2 inventories

Within each topic, the collection provides an overview of issues to consider, methods and approaches adopted by 63 countries, and links to case studies and further resources, including IPCC guidance, case studies, and manuals and publications about methods for collection of new data.

1 UNDERSTANDING TIER 2 APPROACHES FOR LIVESTOCK GHG INVENTORIES

1.1 The importance of livestock in global and national GHG emissions

In 2010, agriculture emitted about 5.4 Gt CO2e, accounting for about 11% of global GHG emissions (Tubiello et al. 2015). Of total agricultural emissions, about 60% is due to livestock emission sources, with enteric fermentation contributing ~63% of livestock emissions, manure management contributing ~12% and deposit of dung and urine on pasture contributing ~25% of livestock emissions. Data from FAO for 185 Parties to the UNFCCC suggests that the main livestock emission sources account for about 16.5% of their total GHG emissions, but exceed 10% of total GHG emissions in 78 countries (i.e. 42% of 185 countries).[1]

In addition to these direct livestock emission sources, further livestock-related emissions occur in feed production and processing and land use change driven by demand for animal feed, as well as in livestock product transport and processing. When these emissions are included, livestock contribute about 14.5% of global anthropogenic emissions, most of which is due to dairy and beef cattle production (Gerber et al. 2013).

Globally, livestock GHG emissions have been contributing an increasing share of agricultural emissions over time (Tubiello et al. 2015). While total GHG emissions from livestock production in developed countries as a whole have declined in recent decades, emissions from cattle, pigs and small ruminants in developing countries have increased significantly (Caro et al. 2014). Further growth in production and consumption of livestock products is projected in developing countries in the coming decades, with the highest increase in total and per capita consumption projected to occur in low- and lower-middle income countries (Robinson and Pozzi 2011). Although some increase in demand will be met by trade with developed countries, GHG emissions from livestock production in developing countries can be expected to continue to increase.

Despite the increase in total emissions from livestock production in developing countries, GHG emission intensity (tCO_2e per tonne of livestock product) has been decreasing (Caro et al. 2014). Increases in the efficiency of livestock production – whether through transformation of livestock production systems or through productivity and efficiency improvements within production systems – are therefore an important way to meet increasing demand for livestock products while limiting impact on the global climate system (Gerber et al. 2013, Havlík et al. 2014). The livestock sector accounts for up to half the technical mitigation potential in agriculture, forestry and land use, and the majority of livestock mitigation options are either costless to producers or have low costs (Herrero et al. 2016, Henderson et al. 2017)

Guidelines from the Intergovernmental Panel on Climate Change (IPCC) for national GHG inventory compilation and reporting provides several methodological options for estimating livestock GHG

[1] FAOSTAT. www.fao.org/faostat/en/?#home

emissions (IPCC 1996, 2000, 2006). Tier 1 methodologies use fixed values for GHG emissions per head of livestock, so changes in total emissions can reflect only changes in livestock populations. Tier 2 methodologies, which require more detailed information on the characteristics and performance of different sub-categories of livestock, are able to better reflect actual production conditions. The global estimates of livestock sector emissions cited above were made using the Tier 1 approach. But measuring the effects of changes in livestock management practices on GHG emissions at the country level requires adoption of a Tier 2 approach that can capture the effects of changes in management and animal performance on GHG emissions. Better characterization of livestock GHG emissions can also assist policy makers to target and design efforts to mitigate GHG emissions in the livestock sector (Wilkes et al. 2017). Given the significance of enteric fermentation emissions and emissions from cattle in many countries' livestock inventories, applying a Tier 2 approach to estimating enteric fermentation emissions is particularly relevant.

Further resources:

Caro, D. et al. (2014). Global and regional trends in greenhouse gas emissions from livestock. *Climatic Change* 126 (1-2): 203-216. https://link.springer.com/article/10.1007%2Fs10584-014-1197-x

Gerber, P. et al. (2013). Tackling climate change through livestock. FAO, Rome. http://www.fao.org/3/a-i3437e.pdf

Havlík, P. et al. (2014) Climate change mitigation through livestock system transitions. *Proceedings of the National Academy of Sciences*, *111*(10): 3709-3714. http://www.pnas.org/content/111/10/3709.short

Henderson, B., Falcucci, A., Mottet, A., Early, L., Werner, B., Steinfeld, H., & Gerber, P. (2017). Marginal costs of abating greenhouse gases in the global ruminant livestock sector. *Mitigation and Adaptation Strategies for Global Change*, *22*(1), 199-224. https://link.springer.com/article/10.1007%2Fs11027-015-9673-9

Herrero, M. et al. (2016). Greenhouse gas mitigation potentials in the livestock sector. *Nature Climate Change*, *6*(5), 452. https://www.nature.com/articles/nclimate2925

Intergovernmental Panel on Climate Change (IPCC) (1996). *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available at:* http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html

IPCC (2000) Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Available at: https://www.ipcc-nggip.iges.or.jp/public/gp/english/

IPCC (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

Robinson, T. and Pozzi F. (2011). Mapping Supply and Demand for Animal-Source Foods to 2030. Working paper. Rome: Food and Agriculture Organization of the United Nations (FAO). www.fao.org/docrep/014/i2425e/i2425e00.pdf

Tubiello, F. et al. (2015). The contribution of agriculture, forestry and other land use activities to global warming, 1990–2012. *Global change biology*, *21*(7): 2655-2660 https://onlinelibrary.wiley.com/doi/full/10.1111/gcb.12865

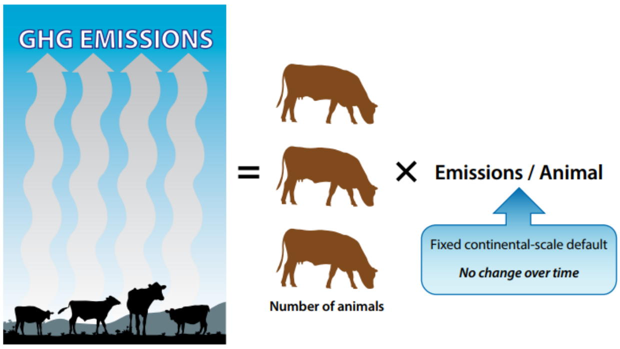
Wilkes A, Reisinger A, Wollenberg E, van Dijk S. 2017. Measurement, reporting and verication of livestock GHG emissions by developing countries in the UNFCCC: current practices and opportunities for improvement. CCAFS Report No. 17. Wageningen, the Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) and Global Research Alliance for Agricultural Greenhouse Gases (GRA). http://hdl.handle.net/10568/89335

1 HOW TIER 2 APPROACHES DIFFER FROM TIER 1 APPROACHES

Guidelines from the Intergovernmental Panel on Climate Change (IPCC) for national GHG inventory compilation and reporting provide different methodological options for estimating livestock GHG emissions (IPCC 1996, 2000, 2006).

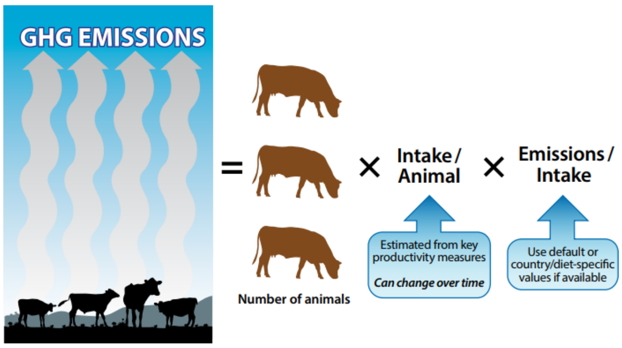
Tier 1 methodologies use fixed values for GHG emissions per head of livestock, so changes in total emissions reflect only changes in livestock populations (Figure 1). This approach assumes that animals of different ages and breeding status have the same emissions and that emissions per head do not vary 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 (Text Box 1). As of 2017, all but 21 developing countries use the Tier 1 IPCC default values for estimating enteric fermentation emissions in their national GHG inventories (Wilkes et al. 2017). Even where countries use national data to develop country-specific emission factors, often these emission factors do not change over time, so similar to Tier 1 default factors, 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.

Figure 1: Tier 1 approach to estimating livestock emissions



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

Figure 2: Tier 2 approach to estimating livestock emissions



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

Tier 2 approaches require more detailed information on different types of livestock in a country, and data on livestock weight, weight gain, feed digestibility, milk yield and other factors reflecting 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 2). This conversion factor changes with the quality of animal diet. 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 (Text Box 2). A Tier 2 approach is therefore essential for capturing the effects of livestock development and climate change mitigation policies on emissions from the sector.

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

- Where livestock emissions are key sources in a national inventory, IPCC Guidelines recommend the use of Tier 2 approaches to more accurately estimate emissions from these sources;
- Tier 2 approaches better reflect national circumstances and the actual production systems within a country (see Text Box 1);
- Tier 2 approaches can better capture changes in emissions intensity (GHG emissions per unit of livestock product output) due to increasing productivity, so Tier 2 approaches can enable countries to track trends in emissions intensity as well as absolute emissions (see Text Box 1). Examples of how emissions and emission intensity change over time at a country level can be found in case studies here: https://globalresearchalliance.org/research/livestock/capability-building/success-stories/
- Tier 2 approaches provide more detail on production systems, and this information can be used to identify a wider range of mitigation options in the livestock sector. Examples of how a Tier 2 approach enables identification and assessment of mitigation options can be found here: http://www.fao.org/in-action/enteric-methane/en/

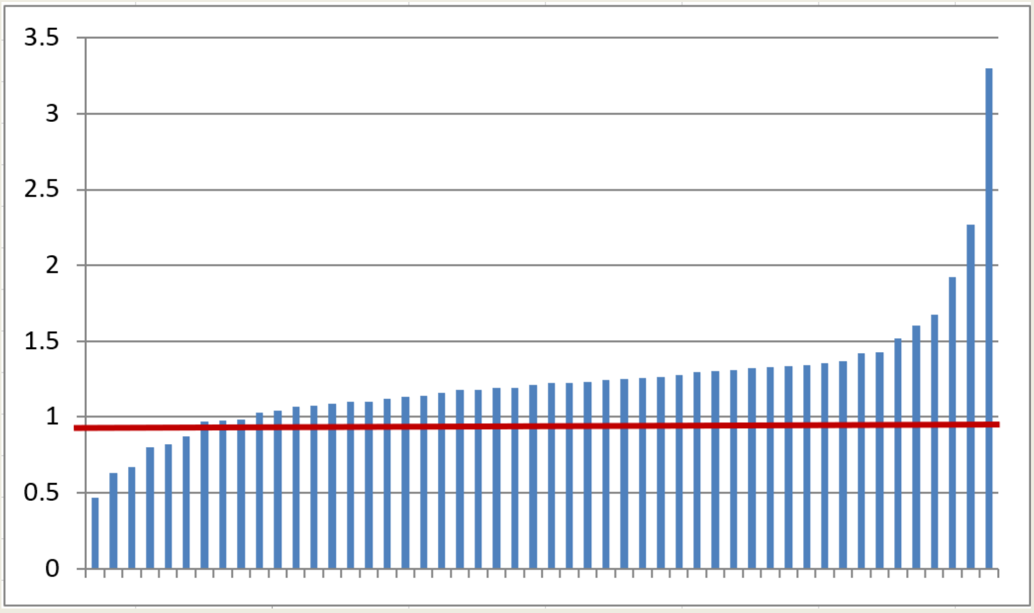
Some countries refer to their approach as a “Tier 2/Tier 3” or “Tier 3” approach. Tier 3 approaches are not clearly defined in IPCC guidance. IPCC (2006) suggests that Tier 3 approaches may use “sophisticated models that consider diet composition in detail, concentration of products arising from ruminant fermentation, seasonal variation in animal population or feed quality and availability, and possible mitigation strategies” and may address factors affecting feed requirements or variations in methane conversion rates. Some of these factors are also considered in country-specific Tier 2 models. Therefore, this collection of Tier 2 cases makes no distinction between Tier 2 and Tier 3 approaches.

Text Box 1 Are emission factors higher or lower when Tier 2 approaches are used, and how do trends in emission intensity change? The example of dairy cattle

Tier 2 approaches are used to estimate enteric fermentation emissions from cattle in 62 countries’ national GHG inventories. National inventory reports from 48 countries provide sufficient information for dairy cattle to compare Tier 1 and Tier 2 emission factors, and comparisons of trends in emission intensity (kg CH_4/kg milk) of dairy production are possible for 28 countries. These comparisons show that using a Tier 2 approach results in emission estimates that better reflect national conditions, and that reductions in emission intensity due to increasing productivity can be tracked if a Tier 2 approach is adopted.

Emission factors: When a Tier 2 approach was used to estimate dairy cattle enteric fermentation emissions, the Tier 2 emission factors were higher than the IPCC default Tier 1 emission factors in 40 out of 48 countries (i.e. 83%) (Figure 3). For countries with a higher Tier 2 emission factor, the average emission factor was 34% higher than the Tier 1 default. In the remaining 8 countries where Tier 2 was lower than Tier 1, the average Tier 2 emission factor was 20% lower than the Tier 1 emission factor. Extremely low and extremely high ratios of Tier 2 to Tier 1 emission factors shown in Figure 3 were mostly for countries whose actual production systems or dairy cattle performance differed significantly from the assumptions underlying the regional IPCC default values (see Inventory Practice: Verification of emission factors in South Africa).

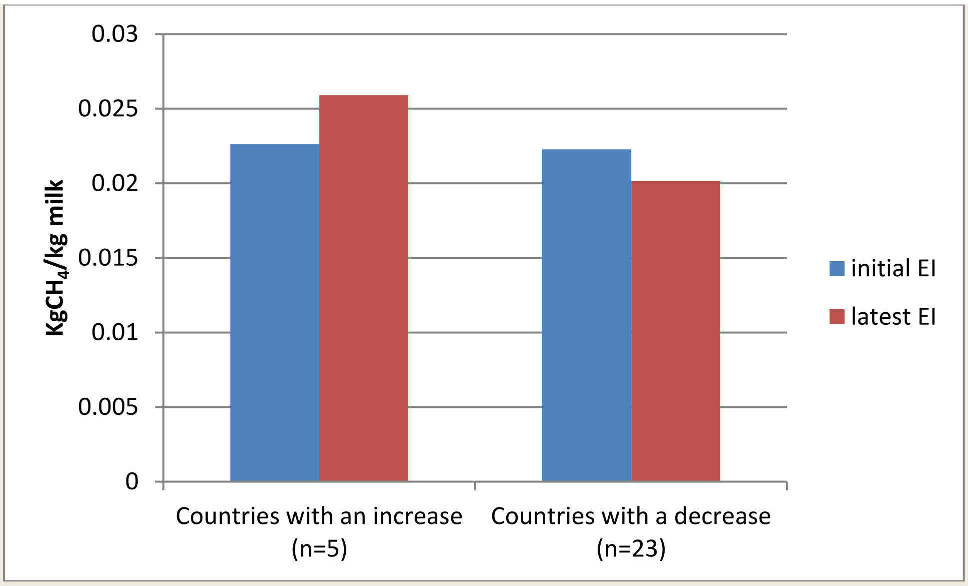
Figure 3: Ratio of Tier 2 to Tier 1 emission factors for dairy cattle



Note: The ratio is calculated as Tier2 dairy cattle emission factor in the first inventory reporting a Tier 2 approach compared to the appropriate default Tier 1 emission factor. A ratio <1 indicates a lower Tier 2 emission factor, and a ratio >1 indicates a higher Tier 2 emission factor.

Trends in emission intensity: Twenty-eight countries reported both annual milk yield per cow and the emission factor in such a way as to enable comparisons of the emission intensity of milk production between the initial use of the Tier 2 approach and the latest reported inventory. In 23 out of the 28 countries, emission intensity decreased (Figure 4). The average reported decrease in emission intensity was 10%. Among the 5 countries where emission intensity increased, the average increase was 13%.

Figure 4: Average change in emission intensity (EI, kgCH_4/kg milk) between the first reported use of a Tier 2 approach and the latest reported inventory



Source: this study

Text Box 2 The use of Tier 2 approaches to reflect changes in emission factor over time

As of 2017, 63 countries used a Tier 2 approach for livestock in their national GHG inventories. Of these, 55 provided sufficient information in the latest national inventory report (NIR) to tell whether the Tier 2 approach is applied in a way that enables updating of emission factors, or whether a static emission factor was used (i.e. the emission factor is country-specific, but remains unchanged between years) (Table 1). For dairy cattle, 45 countries (71%) currently use a dynamic approach, including 8 countries that started with a static emission factor but now have a dynamic inventory system. For other (i.e. non-dairy) cattle, a greater proportion (24%) currently uses a static emission factor, but 17 countries have moved from an initial static emission factor to their current dynamic system. Some countries use a dynamic emission factor for dairy, but a static one for other cattle. Common reasons given include the assumption that there has been no change in the diets of non-dairy cattle and the relatively lower significance of emissions from other cattle in the national inventory.

Table 1: Number of countries using dynamic approach or static EFs for dairy and other cattle emissions

	Dairy cattle			Other cattle		
	Dynamic	**Static**	**Unknown**	**Dynamic**	**Static**	**Unknown**
Initial inventory	37 (58%)	21 (33%)	5 (8%)	22 (35%)	35 (56%)	5 (8%)
Latest inventory	45 (71%)	10 (16%)	8 (13%)	39 (63%)	15 (24%)	8 (13%)

Source: This study

Further resources:

On Tier 1 and Tier 2 approaches for livestock inventories:

Intergovernmental Panel on Climate Change (IPCC) (1996). *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available at:* http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html

IPCC (2000) Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Available at: https://www.ipcc-nggip.iges.or.jp/public/gp/english/

IPCC (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

GRA (n.d.) Livestock development and climate change. https://globalresearchalliance.org/wp-content/uploads/2016/08/Inventory-Brochure_Interactive_final.pdf

Case studies of Tier 2 approaches for assessment of livestock mitigation options:

FAO and GRA. Reducing enteric methane for improving food security and livelihoods project: http://www.fao.org/in-action/enteric-methane/en/

Case studies of how Tier 2 approaches reflect livestock sector trends over time:

GRA success stories in low emission livestock development: https://globalresearchalliance.org/research/livestock/capability-building/success-stories/

1.2 How Tier 2 can help with MRV of mitigation actions and NDCs

The Paris Agreement came into force in November 2016. UNFCCC Decision 1/CP.20 invited Parties to submit their intended nationally determined contributions (INDCs) to the Conference of Parties, and Decision 1/CP.21 invited Parties to communicate their first nationally determined contribution (NDC) by the time the Party ratifies the Paris Agreement. For most countries, their INDC became their first NDC. By April 2018, 175 of the 197 Parties to the UNFCCC had ratified the Paris Agreement. For developed countries, NDCs should be economy-wide absolute emission reduction targets (Paris Agreement, Article 4.4), while developing countries should move toward economy-wide emission reduction or limitation targets over time. Livestock emissions are thus included in the NDCs of most developed countries. Analysis of the INDCs of 150 developing countries shows that 48 countries explicitly mentioned intentions to reduce emissions from livestock-related sources in their INDC, while a further 44 countries include livestock in the scope of their NDC along with the agriculture sector in general or as part of an economy-wide target (Wilkes 2017). In addition, at least 17 countries have proposed nationally appropriate mitigation actions (NAMAs) to reduce livestock-related emissions.

Most developing countries have proposed NDCs in the form of deviations from a business-as-usual emission scenario, although some have proposed absolute emission reductions or reductions in emission intensity (Wilkes et al. 2017). National GHG inventories will be a key tool in measuring and reporting progress in achievement of NDCs. Since few countries propose reductions in absolute numbers of livestock, it will be essential that national GHG inventories are able to reflect changes in management practices and productivity due to livestock sector or climate policy measures. Tier 2 approaches in national GHG inventories will be required. Where countries intend to implement mitigation actions in specific livestock sub-sectors or regions in a country, Tier 2 approaches will also be needed (see Inventory Practice: Aligning national GHG inventories, NDCs and NAMAs in Kenya).

Further resources:

Wilkes, A. (2017) Measurement, reporting and verification of greenhouse gas emissions from livestock: current practices and opportunities for improvement. CCAFS Info Note. Copenhagen, Denmark: CGIAR Research Programme on Climate Change, Agriculture and Food Security (CCAFS). https://cgspace.cgiar.org/rest/bitstreams/147086/retrieve

Wilkes, A. et al. (2017) Measurement, reporting and verification of greenhouse gas emissions from livestock: current practices and opportunities for improvement. CCAFS Info Note. Copenhagen, Denmark: CGIAR Research Programme on Climate Change, Agriculture and Food Security (CCAFS). https://ccafs.cgiar.org/publications/measurement-reporting-and-verification-livestock-ghg-emissions-developing-countries#.WtcgMhsvzIU

GRA (n.d.) Livestock development and climate change . https://globalresearchalliance.org/wp-content/uploads/2016/08/Inventory-Brochure_Interactive_final.pdf

NDC Toolox Navigator: http://ndcpartnership.org/toolbox-navigator#tools

Text Box 3: Data sources used to compile this collection

As of 2017, Tier 2 approaches were used by 63 countries for estimating livestock emissions in their national GHG inventories, including 42 developed countries and 21 developing countries. For this overview of how countries use Tier 2 approaches, information was reviewed from developed country national inventory reports (NIRs) since 2003 that are available on the UNFCCC website.[2] For developing countries, we used NIRs where they could be found either on the UNFCCC website or on national websites, and inventory summaries in national communications and Biennial Update Reports (BURs) where no separate NIR document could be found. Information on the specific practices used by developing countries is more limited, because developing countries are not required to submit full NIRs.

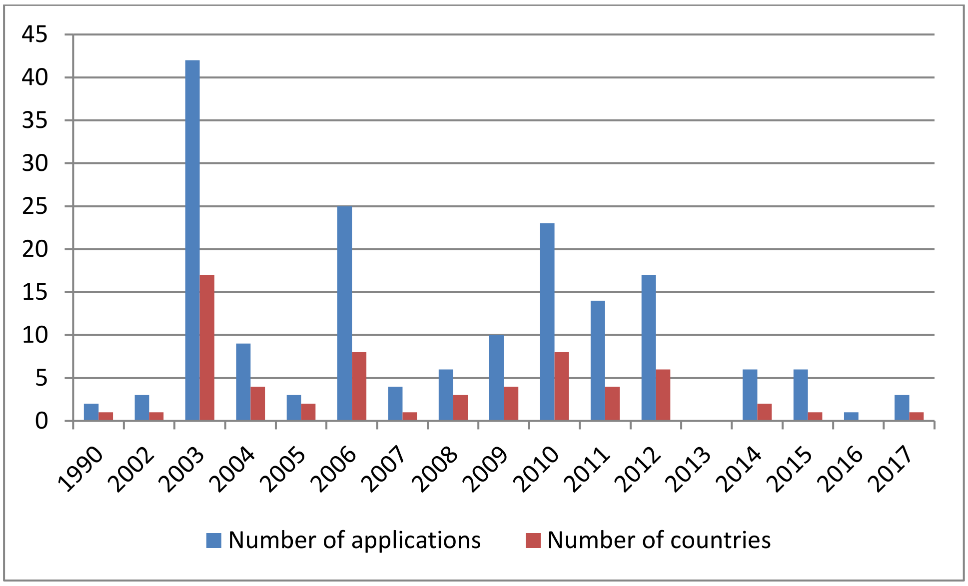
1.3 Overview of how countries use Tier 2 approaches for livestock

How many countries are using a Tier 2 approach?

As of 2017, 63 countries use or have used a Tier 2 approach for one or more types of livestock. A Tier 2 approach is used for enteric fermentation by 62 countries for dairy cattle, 62 countries for other cattle, 32 countries for sheep and 18 for pigs. Together, these livestock types account for about about 80% of global livestock emissions (FAOSTAT). A smaller number of countries have also used Tier 2 approaches for goats, buffalo, equids, deer, reindeer, rabbits and other animal types. About 50% of first applications have occurred in the last 10 years, and just over 45% of countries first used a Tier 2 approach in the last 10 years (Figure 5).

[2] https://unfccc.int/process/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories/submissions-of-annual-greenhouse-gas-inventories-for-2017

Figure 5: Number of countries and instances of first use of Tier 2 approaches from 1990-2017



Most countries applying a Tier 2 approach to enteric fermentation for cattle also apply a Tier 2 approach to CH_4 emissions from manure management, and about one third also apply a Tier 2 approach for cattle manure N_2O emissions (Table 2). More countries use a Tier 2 approach for pig manure management than for enteric fermentation from pigs.

Table 2: Application of Tier 2 approaches to different GHG sources from different livestock types

	Enteric fermentation	CH_4 manure management	N_2O manure management	N_2O pasture deposit
Cattle	62	57	22	11
Sheep	32	18	17	9
Pigs	18	33	18	-

Further resources:

UNFCCC Website for National Inventory Submissions by developed countries:
https://unfccc.int/process/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories/submissions-of-annual-greenhouse-gas-inventories-for-2017

UNFCCC website for National Communication submissions by developing countries:
https://unfccc.int/process/transparency-and-reporting/reporting-and-review-under-convention/national-communications-0

UNFCCC website for Biennial Update Report submissions by developing countries:
https://unfccc.int/process/transparency-and-reporting/reporting-and-review-under-convention/biennial-update-reports-0

1.4 The IPCC Tier 2 model and other country-specific Tier 2 approaches

The IPCC guidelines provide flexibility for how the Tier 2 approach is implemented. The IPCC guidelines elaborate a specific model of enteric fermentation (the 'IPCC model') that is largely based on ruminant net energy models described in NRC (1984, 1989). Other models that are consistent with the IPCC Guidelines may also be used ('country-specific approaches').

For enteric fermentation, the IPCC model has been used in about two thirds of applications for dairy and other cattle. About one third of the total number of Tier 2 applications for cattle use country-specific approaches consistent with the IPCC guidance. Three countries (i.e. Denmark, Ukraine, United Kingdom) began by using the IPCC model but later changed to a country-specific approach (see Country Case Study: Denmark, Country Case Study: United Kingdom). Thus, once a country adopts either the IPCC model or a country-specific approach, most countries tend to stick with the same approach and make improvements over time within that methodological approach.

The IPCC Tier 2 model

The IPCC Tier 2 model is set out in the 1996 and 2006 Guidelines and 2000 Good Practice Guidance. The IPCC model for enteric fermentation is largely based on ruminant net energy models described in NRC (1984, 1989). 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 (Ym, % of gross energy in feed converted to methane). Daily emissions per head are then converted to annual emissions per head:

$$EF_i = [GE_i \bullet Ym_i \bullet 365] / 55.65 \qquad \text{[Eq. 1]}$$

where

i = index of each livestock category
EFi =emission factor (kg CH_4/head/year)
GE = gross energy intake (MJ/head/day)
Ym= 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 model estimates gross energy intake from animal performance data reflecting the net energy required for maintenance, activity, growth, lactation and other functions. To estimate gross energy intake for cattle using the IPCC model, the following data is required for representative animals of each category (IPCC 1996):

- weight (kg)
- average weight gain per day (kg)
- feeding situation (i.e. confined animals; animals grazing good quality pasture; and animals grazing over very large areas)
- milk production per day (kg/day)
- average amount of work performed per day (hours/day)
- percentage of cows giving birth in a year; and
- feed digestibility (%).

The IPCC guidelines also set out tiered approaches for estimating manure management emissions. Once a Tier 2 approach is used for enteric fermentation, the same input data describing feed intake and digestibility are used to calculate volatile solid excretion for estimating methane emissions from manure management. Enhanced characterization of animals and diets can also provide the information required for Tier 2 estimation of nitrous oxide emissions from manure management.

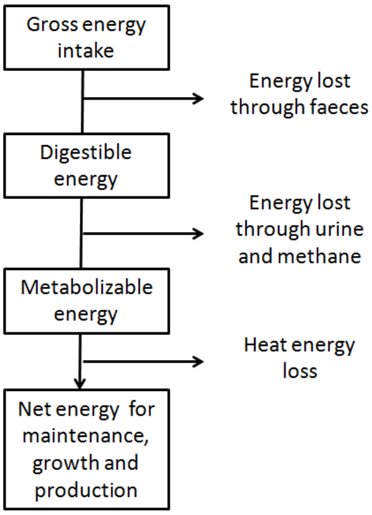
Often, when a country adopts the IPCC Tier 2 model, not all data required for the Tier 2 approach are immediately available. However, default values and other sources of data can be used where statistical data or national research data are unavailable. Chapter 3 of this document describes the different sources of data that countries have used for the various parameters in the IPCC model for enteric fermentation and manure management emissions from cattle, providing a comparison of data sources used in the initial Tier 2 inventory with data sources in subsequent inventories. Country Case Studies for Bulgaria, Estonia and the United Kingdom describe how these countries have implemented the IPCC model for cattle in their national GHG inventories, as well as the improvements they have made over time.

The 2006 IPCC Guidelines recognize the potential for refinement of the IPCC model by using methods that incorporate factors that affect feed demand or feed intake or that affect the methane conversion rate (Ym), such as diet chemical composition. Some countries have implemented such refinements within the framework of the IPCC model. Examples include Slovenia and the United Kingdom, which have developed country-specific methods for estimating feed digestibility that are applied within the framework of the IPCC model (Inventory practice: Estimating digestibility using a country-specific approach in the UK, Inventory practice: Accounting for effects of increased concentrate use on gross energy intake and digestible energy in Slovenia).

Country-specific approaches

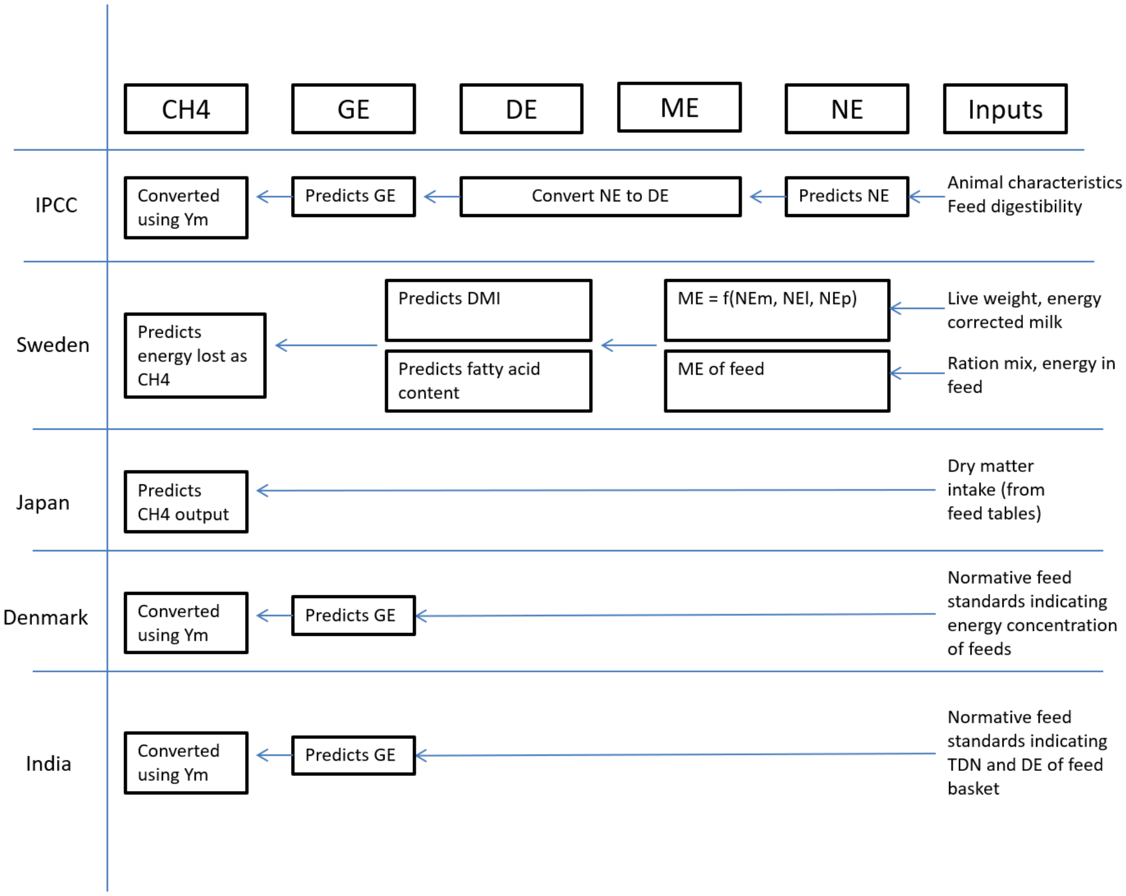
The basic elements of the IPCC approach for enteric fermentation are described in Eq. 1 above. In addition to refinements to the IPCC model aimed at improving estimates of feed intake or methane conversion factors, the IPCC Guidelines (IPCC 2006) encourage the use of Tier 3 approaches that use sophisticated models that consider in more detail diet composition and rumen fermentation processes, or that represent seasonal trends. Several countries have thus implemented country-specific approaches that represent more significant departures from the IPCC model. Many of these approaches can be considered Tier 2 or Tier 3 approaches.

Figure 6: Generic livestock energy balance model



In general, both IPCC and country-specific approaches are based on a common livestock energy balance model that relates gross feed energy intake to net energy for maintenance and production (Figure 6). However, the specific method used to translate animal characteristics, feed characteristics or animal performance into estimates of intake, and the methods used to transform energy intake into methane emissions vary. Descriptions of selected country-specific approaches and their evolution over time are given in the Country Case Studies for Austria, Colombia, Denmark, India, Ireland, Japan, The Netherlands, New Zealand and Sweden. Figure 7 provides a stylized overview of some of these countries' approaches in comparison to the IPCC model.

Figure 7: Selected country-specific approaches in comparison to the IPCC model for enteric fermentation



The reason why countries have adopted their country-specific Tier 2 approach varies. Common factors reflected in country-specific approaches include:

- **Country context:** Several countries' model was developed to better account for feed characteristics. For example, several European countries' approach was developed to specifically account for emissions when dairy rations have a higher content of highly digestible feed, such as concentrate, silage or sugar beet (e.g. Ireland, Denmark, United Kingdom). Australia's approach (later adapted by New Zealand) was specifically elaborated for grazing livestock systems.
- **Existing energy balance models:** Country-specific approaches, including underlying energy balance models and methane production models, have been developed on the basis of existing models used in the livestock sector. For example, Denmark's country-specific approach is based on the Danish Normative System for formulating feeding plans; Sweden's inventory approach is based on the NORFOR feed evaluation system used by Swedish dairy farmers. Ireland's inventory approach is based on the French INRA nutrition system, which was widely used by Irish farmers when they adopted a Tier 2 approach. These feed and energy balance models in most cases pre-existed the GHG inventory Tier 2 approach. As these models evolved, so did the approach in these countries' GHG inventories.
- **Existing extension tools and datasets:** Feed tables and other analytical tools are primarily developed to help farmers improve cattle nutrition. Several tools are linked to databases containing animal recording information, and these datasets are used by some countries as a key source of information to characterize 'typical' diets and farm management practices

(e.g. Inventory practice: Use of existing data on cattle diets in Denmark), to directly provide activity data (e.g. milk production data used in Sweden's inventory) or both (Inventory Practice: TINE BA cow recording system in Norway).

- **Prior and ongoing research:** These energy balance models and extension tools were generally based on prior research. As research continues, these resources have been updated, and the approach to enteric fermentation modelling in GHG inventories has evolved alongside them. This has included changes in how rumen function is modelled (e.g. Netherlands), how energy balance is modelled (e.g. Sweden), and research on methane conversion factors (e.g. New Zealand). Much of this research has been primarily motivated by animal nutrition objectives, rather than inventory needs alone.
- **Broader environmental policies:** Several European countries' inventory approaches were strongly shaped by monitoring systems set up in relation to nitrate pollution in the early 1990s (e.g. Norway, Austria) and/or informed by prior research on feed intake and feed characteristics conducted to inform nitrate pollution control policies.

Many of the knowledge resources used in developing and applying country-specific approaches may also be applicable within the IPCC model. Examples of how these resources are used to meet specific inventory needs are described in the inventory practice case studies.

Further resources:

IPCC Guidance on Tier 2 approaches:

Intergovernmental Panel on Climate Change (IPCC) (1996). *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Available at:* http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html

IPCC (2000) Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Available at: https://www.ipcc-nggip.iges.or.jp/public/gp/english/

IPCC (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

Case studies of Tier 2 inventories in practice:

Country livestock GHG inventory case studies

Inventory practice case studies

2 PLANNING TIER 2 INVENTORIES

The IPCC Guidelines provide detailed guidance on many aspects of inventory compilation using a Tier 2 approach. Based on a review of all current Tier 2 applications for cattle, this section highlights:

- technical considerations that may affect decisions about the structure of the inventory approach;
- processes and models to facilitate compilation of a Tier 2 inventory; and
- institutional dimensions of inventory compilation.

It also provides links to resources to help in planning for inventory compilation.

2.1 Technical dimensions of structuring a Tier 2 inventory

This section highlights factors that are considered in decisions about:

- which livestock types of apply a Tier 2 approach to;
- how livestock are characterized in Tier 2 approaches;
- how Tier 2 approaches are linked with methods for estimating manure management emissions; and
- how the availability of data, information and other knowledge resources in the livestock sector may influence the choice of technical approach to inventory compilation.

Key category analysis and choice of tiered approach

Identification of key categories in a national inventory enables limited resources to be targeted to the improvement in data and methods for inventory categories that have significant effects on total absolute emissions, the trend in emissions, or both. IPCC guidance recommends that higher tier methods should be used for key categories. Analysis of 140 livestock inventories from developing countries has found that less than half reported having conducted key category analysis (Wilkes et al. 2017). For many countries, therefore, conducting key category analysis would help in identifying the emission sources to prioritise for targeting of limited available resources.

The IPCC guidelines set out in detail procedures for identification of key categories in the national inventory (IPCC GPG 2000, IPCC 2006 Vol 1 Ch 4). The guidelines set out two approaches to key category analysis:

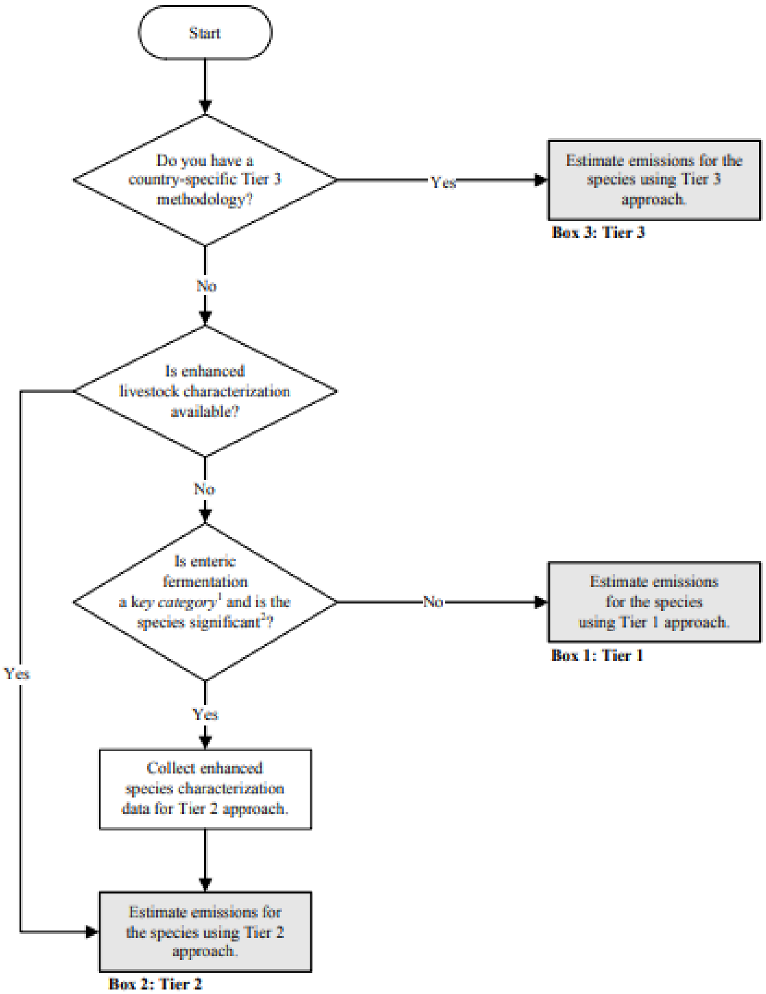
- **Approach 1 level assessment:** Key categories are those that, when summed together in descending order of magnitude, add up to 95 percent of the total level of emissions in the inventory.
- **Approach 1 trend assessment:** Key categories are those whose trend is different from the trend in total emissions, weighted by the level of emissions or removals in the base year.
- **Approach 2:** The Approach 1 level and trend assessment results are weighted by the percentage uncertainty of each emission category, and key categories are those that add up

to 90% of the total sum of uncertainty-weighted emissions in a given year, or 90% of the total sum of the uncertainty-weighted trend in emissions.

For livestock, IPCC (2006) recommends that key category analysis should be applied to the main livestock emission categories (e.g., enteric fermentation, manure management), and if these categories are identified as key, it should then be determined which animal species are significant contributors to these emissions. Emissions from these species should then be estimated using higher tier approaches, where possible (Figure 8). Other criteria mentioned in the IPCC guidance include using Tier 2 for enteric fermentation or manure management emissions:

- if the data used to develop the IPCC default values do not correspond well with the country's conditions; or
- if the country has a large population of cattle, buffalo, or swine; or
- if emissions from a livestock type or sub-type are a large portion of total methane emissions for the country.

Figure 8: Decision tree for choice of methodological tier (IPCC 2006)



Source: IPCC 2006 vol 4 ch 10.

Reflecting the contribution of livestock to emission inventories and the prioritization of resources, among the 63 countries that use a Tier 2 approach for livestock emissions:

- one country applies a Tier 2 approach to dairy cattle only;
- 27 apply a Tier 2 approach to both dairy and other cattle types;
- 17 apply Tier 2 to cattle and one additional type of animal; and
- the remaining 18 countries use Tier 2 approaches for both types of cattle and two or more other species.

Many countries began by applying a Tier 2 approach to one type of livestock, and subsequently applied it to other livestock types over time.

For countries considering adopting Tier 2 approaches, in addition to the results of key category analysis, other factors that may be relevant to consider include:

Prioritization of limited resources: As shown in Chapter 3, many countries' initial Tier 2 inventory uses a variety of data sources, including IPCC default data, expert judgement and data from other countries' inventories or literature, so compiling an initial Tier 2 inventory need not require extensive primary data collection. However, selecting livestock types or sub-types for an initial Tier 2 approach can target the use of limited resources for national inventories, and provide experience that can later be applied to other livestock types. Key category analysis may identify a large number of inventory categories. The United Kingdom applies a ranking tool to help identify priority categories for improvement (Inventory practice: Prioritization of key categories in the United Kingdom's inventory).

Alignment of national GHG inventory with livestock development and climate policy goals: Where countries intend to capture the effects of livestock development or GHG mitigation policies in their national GHG inventories, a Tier 2 approach will be needed. Inventory improvements can be targeted to those sub-sectors or regions where it is expected that policy interventions will affect the trend in emissions (Wilkes et al. 2017; Inventory Practice: Aligning national GHG inventories, NDCs and NAMAs in Kenya)

Further resources:

IPCC (2000) Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Chapter 7 Methodological Choice and Recalculation. Available at: https://www.ipcc-nggip.iges.or.jp/public/gp/english/

IPCC (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 1 Chapter 4 Methodological Choice and Identification of Key Categories. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

Livestock characterization

IPCC guidelines (2006) states that livestock population subcategories should be defined to create relatively homogenous sub-categories of animals that reflect country-specific variations in animal characteristics and feed within the overall livestock population. The IPCC Guidelines (2006) give general guidance on representative livestock sub-categories. For example, it is recommended to categorize cattle into a minimum of 3 sub-categories: mature dairy, other mature cattle and growing cattle. Suggestions on further sub-categories are also made (Table 3).

Table 3: Representative cattle sub-categories identified in the IPCC (2006) 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 • Feedlot-fed cattle on diets containing >90% concentrates

Source: IPCC (2006) Vol. 4 Ch. 10

Livestock characterisation is a critical step in the development of a Tier 2 approach. It determines how country-specific conditions are reflected in the inventory, and the level of disaggregation of activity data required for estimating GHG emissions. It thus determines the feasibility and complexity of inventory compilation. So how do countries categorize cattle in practice?

Dairy cattle: Countries categorize dairy cattle into between 1 and 156 subcategories, with an average of about 8 sub-categories. Among the 63 countries reviewed, 66% report only one category of dairy cattle (i.e. mature, female, used for milking). In some cases, this reflects the definition of dairy cattle in national livestock statistics. In other cases, significant differences in management or animal performance within the country have been taken into consideration and further sub-categories of dairy cattle have been defined on the basis of geographic region (9 countries), production system (5 countries), breed (3 countries) or productivity (1 country). Where countries report only one category of dairy cow, replacement animals and other cattle in dairy production systems are reported in the 'other cattle' category (see Inventory Practice: Characterization of dairy cattle).

Table 4: Frequency of using different criteria to characterize sub-categories of non-dairy cattle

Criterion	Age	sex/physiological status	breed	production system	Use	region
Frequency	55	51	8	9	20	11

Other cattle: Countries categorize non-dairy cattle into between 1 and 416 sub-categories, with a modal number of 7 sub-categories (Table 4). Categorization based on age, and sex or physiological status are most commonly used, but some countries also categorize based on the use of each animal category (e.g. slaughter animals, replacement heifers), geographical region, production system or breed. For example, Georgia has categorized cattle into two breeds to account for significant differences in performance between traditional late maturing breeds and more recently introduced early maturing breeds (see Inventory Practice: Livestock characterization and herd structure modeling in Georgia). In Austria, 18% of the farm area is now under organic production, and categorization of non-dairy cattle distinguishes between organic and conventional production systems to account for significant differences in feed types between these two production systems (see Country Case Study: Austria).

Data availability is one common determinant of the choice of livestock characterization approach. Revision of the inventory approach to make better use of available data is clearly shown in the inventory practice case studies describing livestock characterization in Uruguay and regionalization of the dairy cattle emissions inventory in New Zealand. New Zealand's experience shows that regional categorization of livestock may not increase accuracy of the inventory in any given year, but if regional categorization enables better data to be used to characterize livestock sub-populations, it may improve the ability of the inventory to track changes in animal performance over time.

Where data on livestock sub-populations is missing, alternative data sources have also been used, such as:

- herd modeling used in Georgia to produce estimates of sub-populations of each type of breed included in the inventory (see Inventory Practice: Livestock characterization and herd structure modeling in Georgia);
- interpolation and trend extrapolation used to fill gaps in the time series of sub-populations (see Inventory practice: dealing with missing data for livestock characterization in Austria).

Where data to characterize livestock management practices and performance for livestock sub-categories are missing, methods used include expert working groups (e.g. in Uruguay), regional workshops to elicit expert opinion (e.g. in Colombia) or structured expert judgement elicitation processes (see Inventory practice: structured elicitation of expert judgement in Canada; Inventory practice: estimating digestible energy and methane conversion rates for feedlot cattle in the USA).

Further resources:

IPCC (2000) Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Chapter 4 Agriculture. Available at: https://www.ipcc-nggip.iges.or.jp/public/gp/english/

IPCC (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4 Chapter 10 Emissions from Livestock and Manure Management. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

Inventory practice case studies

Enteric fermentation and manure management linkages

Following the IPCC Guidelines (2006), Tier 2 characterisation of livestock sub-categories enables disaggregated estimation of feed intake for estimating enteric fermentation emissions. The same feed intake estimates should then be used for estimates of manure and nitrogen excretion rates in methane and nitrous oxide emissions from manure management. There are also links between the livestock characterization approach and estimation of manure management methane emissions, because the latter should be estimated in line with the distribution of climate regions within a country (IPCC 2006 Vol 4, Ch 10, 10.41).

In view of these interlinkages, some countries have developed structured data management processes to ensure accurate and consistent estimates of emissions from enteric fermentation and manure management sources. For example, Denmark's national GHG inventory uses the Integrated Database Model for Agricultural Emissions (IDA), which collates data required for GHG inventory calculations as well as inventories of other environmental pollutants, such as ammonia (see Inventory Practice: Integrated data management in Denmark). The use of integrated data management systems is relatively common in Europe, where since the early 1990s the EU Nitrates Directive has required member states to control agricultural nitrate pollution sources.

Further resources:

IPCC (2000) Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Chapter 4 Agriculture. Available at: https://www.ipcc-nggip.iges.or.jp/public/gp/english/

IPCC (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4 Chapter 10 Emissions from Livestock and Manure Management. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

Existing data, information and other resources in the livestock sector

How a country implements the IPCC Tier 2 model or a country-specific Tier 2 approach is often strongly influenced by the availability of knowledge and data resources in the livestock sector. Common types of information resource that are used in inventory compilation include:

- feed tables
- energy balance models
- animal recording systems or herd registers, and
- datasets created for extension or other purposes.

The use of feed tables: Many countries, including those that use the IPCC model and country-specific models, use feed tables to estimate various parameters. Feed tables are often used to quantify the energy content of specific feeds, the mass of which is estimated from other sources (e.g. Country Case Study Ireland; Inventory Practice: estimating digestibility using a country-specific approach in the UK). In other cases, DMI or gross energy intake is directly estimated from feed tables (Country Case Study Austria, Country Case Study: India, Inventory Practice: The use of the Danish Normative System to estimate gross energy). This method assumes that farmers' feeding practices are in line with the recommendations of feed tables. In relatively developed livestock sectors, this may be a reasonable assumption, especially where the feed tables are based on surveys of actual feeding plans. Elsewhere, this assumption may not hold, and alternative methods for estimating feed intake may be more appropriate (Goopy et al. 2018). Where countries lack national feed tables, feed tables or nutritional norms from other countries are sometimes used (Country Case Study Ireland). The Feedipedia website (www.feedipedia.org) provides information on the nutritional content of a large number of fodder and feed types, as well as links to ration formulation tools and other resources.

The use of energy balance models: Several countries use livestock energy balance models that were originally developed to inform farm advisory services. For example, the Danish inventory estimates the methane conversion factor using the Karoline model (Country Case study: Denmark, Inventory practice: The use of the Karoline model to predict methane yield) and the Swedish inventory uses the NORFOR model (Country case study: Sweden). The Netherlands has also developed a country-specific model to account for the high nutritional quality of dairy rations (Inventory practice: modelling rumen processes in The Netherlands). The UK initially used the Feed into Milk model of dairy cow metabolism to estimate digestibility of dairy cow feed intake (Inventory Practice: estimating digestibility using a country-specific approach in the UK), and later expanded use of the model in the inventory (Country case study: UK). Where countries do not have an energy balance model developed in the country, most use the IPCC model, but some use models from other countries. Colombia has recently begun to use a generic model developed for tropical regions, undertaking national studies to validate the model for use in its national inventory (Country Case Study: Colombia).

The use of animal recording systems and herd registers: Delivery of farm advisory services often involves ongoing collection of farm data. Other databases exist because of livestock monitoring schemes, or herd registers compiled for breeding purposes. Statistical reporting systems and farm management surveys are also widely used to characterize livestock, feed sources and other management practices. Some countries use these databases directly as a source of inventory data, while others use the databases to provide estimates of specific parameter values (see Country Case: Denmark, Inventory Practice: Use of existing data on cattle diets in Denmark, Inventory Practice: Estimating milk yields in Slovenia). Although the data collected may not always be statistically representative of the whole livestock population, they are often the best available data, and their suitability for the GHG inventory may need to be verified. The existence of specific data sources may also influence the choice of methodological approach used for inventory compilation (Inventory Practice: The role of cow recording systems in Norway's Tier 2 approach).

Further resources:

Feedipedia: www.feedipedia.org

FAO. 2012. Conducting national feed assessments, by Michael B. Coughenour & Harinder P.S. Makkar. FAO Animal Production and Health Manual No. 15. Rome, Italy.

FAO. 2016. Development of integrated multipurpose animal recording systems. FAO Animal Production and Health Guidelines. No. 19. Rome.

Goopy, J. et al. 2018. A new approach for improving emission factors for enteric methane emissions of cattle in smallholder systems of East Africa – Results for Nyando, Western Kenya. Agricultural Systems, 161: 72-80

2.2 Processes and tools for structuring data compilation and management

The 2006 IPCC Guidelines (Vol 1 Chapter 2) provides generic guidance on data collection for inventory compilation. Methodological principles underlying the good practice set out therein are:

- 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 (e.g. resource prioritisation, planning, implementation, documentation) 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.

In practice, countries use a variety of data sources when they establish their initial Tier 2 approach for enteric fermentation (see Chapter 3). Often the initial Tier 2 approach is developed on an ad hoc basis and subsequently improved over time. Among the diverse tools used, four have commonly been used to help structure the data collection and inventory compilation process:

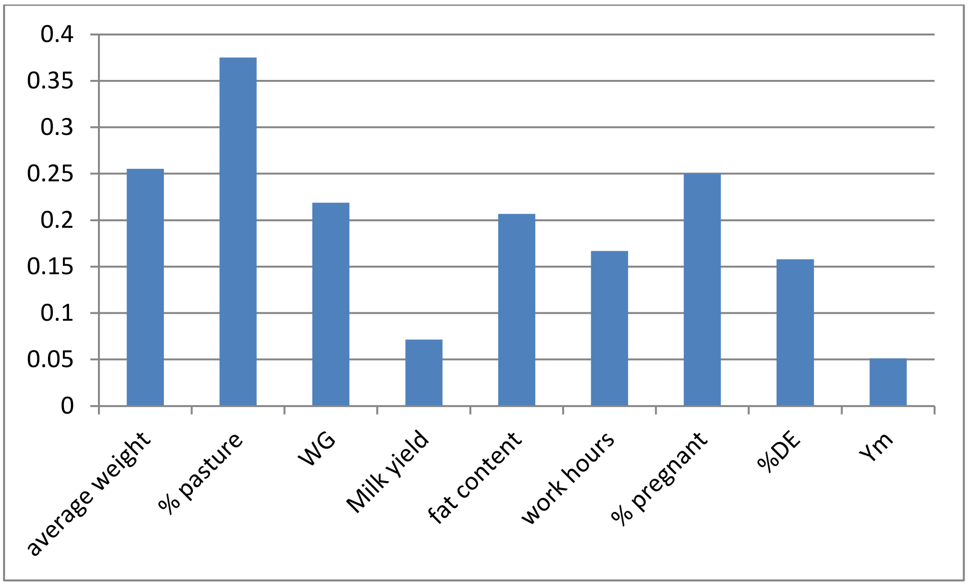
- structured elicitation of expert judgement
- commissioned inventory design
- herd dynamics models, and
- inventory databases and data management systems.

Expert judgement processes

The 2006 IPCC Guidelines (Vol 1 Chapter 2) recognizes that expert judgement on methodological choice and choice of input data is fundamental to inventory development. Specific guidance on eliciting expert judgement is given in Annex 2A.1 to that chapter.

Analysis of 63 Tier 2 livestock inventories shows that for enteric fermentation by cattle, expert judgement was used by more than 20% of countries for initial estimates of animal weight and weight gain, proportion of time spent grazing, fat content of milk and proportion of cows giving birth (Figure 9).

Figure 9: Proportion of countries reporting use of expert judgement as a data source for various parameters



Expert judgement is applied in different ways. In some cases, data on specific parameters is entirely lacking, and data values are estimated by expert judgement. In other cases, various data sources are available, and the most appropriate data values are selected on the basis of expert judgement (e.g. Inventory practice: Improving estimates of live weight in New Zealand). Beyond these ad hoc uses of expert judgement for specific variables, structured expert judgement processes have also been used to compile data for an initial Tier 2 inventory. This is particularly useful where official data is limited and/or where production systems are extremely diverse and data availability is uneven. Examples using surveys of livestock experts and expert workshops are given in Inventory practice: Structured elicitation of expert judgement in Canada's national inventory, Inventory practice: Determining manure management practices in Canada, Inventory practice: Estimating digestible energy and methane conversion rates for feedlot cattle in the USA and Country Inventory Case Study: Colombia.

Further resources:

IPCC (2006) 2006 IPCC Guidelines, Vol. 1, Ch. 2: Approaches to data collection. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/1_Volume1/V1_2_Ch2_DataCollection.pdf

Linstone H. & Turoff M. (eds) (1975) The Delphi Method: Techniques and Applications. Addison-Wesley, Reading, MA.

Commissioned inventory design

Several countries' initial Tier 2 approach was achieved by commissioning design of the inventory. Country case studies from Ireland, New Zealand and Sweden all give examples where scientists from national agricultural research institutes were commissioned to elaborate the structure, methodology and data for the initial Tier 2 inventory. This can be useful where responsibilities for inventory compilation lie with a government ministry, but where the technical knowledge required for the Tier 2 approach is in the research community. Tier 2 inventories often evolve over time. Commissioned reviews and revisions play key roles in improving Tier 2 approaches, both through incremental improvements and through thorough revisions to the initial approach adopted (Country Case Study New Zealand; Country Case study Sweden; Inventory Practice: New Zealand's agriculture advisory panel).

Further resources:

Braatz et al. (2005). Managing the National Greenhouse Gas Inventory Process. UNDP. www.undp.org/content/undp/en/home/librarypage/environment-energy/low_emission_climateresilientdevelopment/managing-the-national-greenhouse-gas-inventory-process.html

Inventory herd models

Some countries' livestock emission inventories are based on models of livestock population dynamics. These models use national data on births, deaths and slaughter to model livestock sub-populations on a monthly basis, together with data on the characteristics of each sub-population, enabling a more accurate representation of annual emissions. Examples are given in Country Case Study: New Zealand and Inventory Practice: Livestock characterization and herd structure modelling in Georgia. These models provide a structure for inventory compilation as they set out the data parameters required. Reviews of the suitability of the model assumptions and data used can be undertaken to improve inventory accuracy over time (Inventory Practice: New Zealand's agriculture advisory panel).

Further resources:

Muir et al. (2011) A review of New Zealand's national methane inventory model. MAF Technical Paper 2011/76 https://www.mpi.govt.nz/dmsdocument/2562/loggedIn

Republic of Georgia (2017) GHGs National Inventory Report of Georgia 2010-2013. https://unfccc.int/files/national_reports/non-annex_i_parties/biennial_update_reports/application/pdf/ghg_national_inventory_report__georgia.pdf

USA (2017) Methodology for estimating CH_4 emissions from enteric fermentation. Annex 3.10 in National Inventory Report. https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/submissions/national-inventory-submissions-2017

Inventory databases and data management systems

Inventory databases serve to structure data compilation and data management activities. Inventory databases can be designed in different ways with different capabilities, including:

- aggregation and storage of activity data, emission factors, and calculated emissions totals;
- data analysis and emission calculations;
- documentation of procedural information and published national inventory methodologies;
- facilitating quality assurance and quality control (QA/QC);
- reporting to the UNFCCC or another entity;

- data sharing among the national inventory team, government agencies, and others; and
- archiving of datasets, calculations, documentation, relevant studies, communications among inventory team members, and final submitted reports.

Some examples (not specific to the livestock sector) have been reviewed by Damassa et al. (2015). See also Inventory Practice: Integrated data management in Denmark. Data management systems can help facilitate collaboration among multiple agencies involved in inventory compilation, and contribute to the broader goals of inventory sustainability, transparency and consistency. Specialist inventory software can also support these objectives (Text Box 4).

Text Box 4: Comparison of IPCC and ALU softwares for livestock Tier 2 approach

Two commonly used inventory softwares are the IPCC Inventory Software (https://www.ipcc-nggip.iges.or.jp/software/index.html) and Agriculture and Land Use Greenhouse Gas Inventory (ALU) Software (https://www2.nrel.colostate.edu/projects/ALUsoftware/). Both softwares cover all IPCC inventory sectors and categories, including livestock. In general, the functionality of each software is broadly similar (see Pulhin 2017). But for livestock their functionalities are different (Table 5). In the IPCC software (Version 2.5.4), users can define sub-categories of each livestock type and enter user-defined emission factors (e.g. Tier 2 emission factors) in place of the Tier 1 default values. However, the IPCC software cannot be used to develop Tier 2 emission factors for each livestock sub-category. ALU software, on the other hand, can be used to enter the secondary activity data required to estimate an emission factor for each sub-category of animal.

Table 5: Comparison of IPCC and ALU software functionalities for livestock

Features	IPCC software (v 2.5.4)	ALU software (v 6.0)
User can define sub-categories of livestock	✓	✓
User can define manure management systems for each sub-category of livestock	✓	✓
User can define % of population of each sub-category in different climate zones	✓	✓
User can choose to use IPCC Tier 1 default emission factors	✓	✓
User can input parameter values to estimate Tier 2 enteric fermentation emission factors	×	✓
User can input parameter values to estimate Tier 2 manure management methane emission factors	×	✓
User can input parameter values to estimate Tier 2 manure management N_2O emission factors	×	✓
User can input activity data and emission factor uncertainty values	✓	✓

Further resources:

IPCC Inventory Software: https://www.ipcc-nggip.iges.or.jp/software/index.html

ALU software: https://www.nrel.colostate.edu/projects/alusoftware/home

Pulhin, F. (2017) Comparison of IPCC 2006 and ALU software. In Manahan, A. (ed) Information Matters, Philippines: Orientation-Workshop on IPCC 2006 Guidelines & Software for Greenhouse Gas Inventories for

AFOLU. Available at https://www.transparency-partnership.net/system/files/document/7th_Capacity_Building_training_report.pdf

Damassa et al. 2015. Data management systems for national greenhouse gas inventories: insights from ten countries. https://www.wri.org/sites/default/files/WRI_Data_management_systems_national_GHG_inventories2.pdf

2.3 Institutional dimensions of implementing a Tier 2 inventory

Developed countries' GHG inventory systems have been designed to meet annual reporting obligations. Developing countries do not have annual reporting obligations. Many developing countries submitted their second national communication to the UNFCCC 10 years after their first communication, and their third on average more than 5 years later (Wilkes et al. 2017). The requirement to submit Biennial Update Reports, including an update to the national GHG inventory, was agreed in 2011. Many countries are still in the process of shifting from institutional arrangements designed for infrequent GHG inventory compilation to institutionalized approaches to enable more regular reporting.

The institutional arrangements developed in each country depend on arrangements for the overall inventory, not just the livestock inventory. But the way Tier 2 inventories are structured has implications for the inventory compilation processes and institutional arrangements required to accomplish regular compilation. Institutional arrangements can broadly be categorized into centralized and decentralized arrangements:

- **Centralized compilation by inventory compilation agency with activity data supply under MoUs, data sharing agreement or contract**: In Austria, Canada and Norway, a Tier 2 approach that uses data from a limited number of data sources facilitates centralized data compilation. In Denmark, the use of centralized databases facilitates collection of data from multiple sources on an annual basis for centralized compilation of the inventory (Inventory Practice: Integrated data management in Denmark).

- **Decentralized compilation prior to submission to inventory compilation agency:** In Finland and the UK, livestock emission sources are estimated by entities under MoU or contract to the inventory compilation agency. Inventory agencies may retain roles in overall management of the inventory process, QA/QC and inventory improvement planning. In the Netherlands, the inventory is accomplished by working groups that coordinate data complilation and calculations prior to submission to inventory compilation agency (Country Case Study: The Netherlands).

In addition to institutional arrangements for inventory compilation, many countries have developed institutional mechanisms to enable QA/QC activities, and review and continual improvement of the livestock inventory (e.g. Inventory Practice: New Zealand's agriculture advisory panel).

Further resources:

Capacity Building Initiative for Transparency https://www.thegef.org/topics/capacity-building-initiative-transparency-cbit

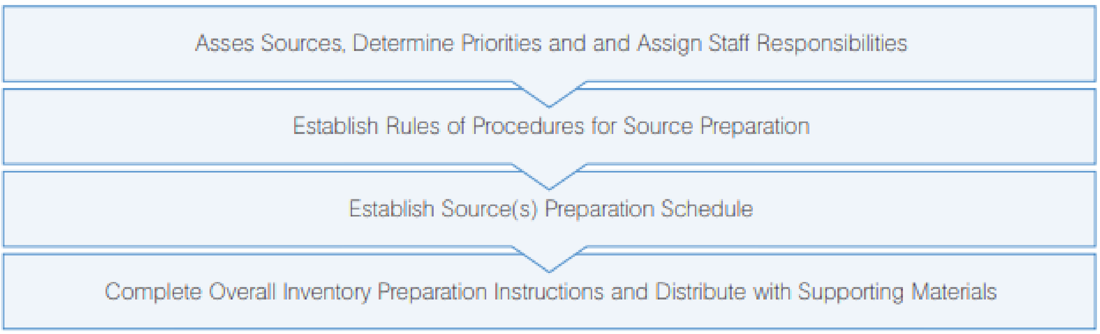
US EPA national GHG inventory capacity building https://www3.epa.gov/climatechange/Downloads/EPAactivities/TMPzrk3zr.htm#Approach

Toolkit on establishing and maintaining institutional arrangements for preparing national communications and biennial update reports: http://unfccc.int/files/national_reports/non-annex_i_natcom/training_material/methodological_documents/application/pdf/unfccc_mda-toolkit_131108_ly.pdf

2.4 Operational planning for a Tier 2 inventory

General guidance on implementation planning for national GHG inventories provided by the UNFCCC describes four main steps for source-specific planning (Figure 10). Further detailed steps are set out in general guidance presented in UNDP (2005). Many developed countries' national inventory reports present a summary of the process for elaboration of the national inventory, including implementation plans. An example is provided in Inventory Practice: Institutional arrangements for compilation of Norway's livestock emission inventory. There are few examples of operational plans for countries preparing their initial Tier 2 livestock inventory. However, Inventory Practice: Operational planning for a Tier 2 inventory in Kenya provides an example of an action plan from an ongoing inventory improvement process.

Figure 10: Source-specific planning tasks outlined in UNFCCC Guidance



Source: https://unfccc.int/resource/docs/publications/09_resource_guide3.pdf

Further resources:

UNFCCC (2009) UNFCCC Resource Guide for Preparing the National Communications of non-Annex 1 Parties. Module 3: National GHG inventories. Available at https://unfccc.int/resource/docs/publications/09_resource_guide3.pdf

UNDP (2005) Managing the national GHG inventory process. Available at: http://www.undp.org/content/undp/en/home/librarypage/environment-energy/low_emission_climateresilientdevelopment/managing-the-national-greenhouse-gas-inventory-process.html

3 DATA COLLECTION AND COMPILATION OF TIER 2 LIVESTOCK INVENTORIES

The IPCC (2006) decision tree for adoption of a higher tier approach suggests that a Tier 2 approach should be used where livestock emissions are a key source and data is available, or if data is not available then data should be collected. The IPCC (2006, Vol. 1 Ch. 2) also gives general guidance on data collection approaches, including gathering existing data and collecting new data, and specific guidance on data sources for the Tier 2 approach for livestock (IPCC 2006 Vol. 4 Ch.10). For countries considering adopting a Tier 2 approach in their livestock inventory, limited data availability is often considered to be a major constraint. Common questions include:

- Do we need to have official agricultural statistics for each parameter in the IPCC equations?
- Do we need nationally representative survey data if there are no official statistics?
- If our country lacks data for certain parameters, can we still adopt a Tier 2 approach?
- Can we still use IPCC default values for certain parameters?
- If we have a national feed standard, can we use this instead of the IPCC's recommended approach?

This chapter provides insight into these and other questions by summarizing the actual data sources reported in Tier 2 inventories for cattle. It also provides links to case studies of inventory practices illustrating how countries have dealt with practical challenges in data collection and inventory compilation. The information presented is based on a review of the initial and latest inventory reports (2017) available for 63 countries that have used a Tier 2 approach. The examples are limited to Tier 2 approaches for cattle, because most Tier 2 approaches have been applied to cattle. The review covers livestock population data, and data for estimating enteric fermentation and manure management methane emissions.

3.1 Livestock population data sources

Table 6 shows the frequency of using different sources of data for livestock populations. Most countries obtain the data from national statistical agencies, ministry of agriculture or other government agencies. In four countries, producer organisations hold the data on livestock populations and three countries used animal registration databases.

Table 6: Frequency of sources of livestock population data (n=63)

Data source	Frequency
Statistical Agency	40
Ministry of Agriculture	15
Other government agency	6
Producer organisations	4
Extrapolation	7
Expert judgment	3
Animal registration database	3
Publication	1
Modelled	2
FAOSTAT	1

However, full population data is not always available for a complete time series for all livestock population types. Alternative data sources and methods to fill data gaps used by some countries include

- extrapolation from years with data (e.g. Inventory Practice: Dealing with missing data for livestock characterization in Austria, Inventory Practice: Estimating livestock population time series in Romania, Inventory Practice: Livestock population estimates in Croatia);
- estimating the population of livestock sub-categories using models of herd dynamics (e.g. Inventory Practice: Livestock characterization and herd structure modelling in Georgia);
- expert judgement; and
- publications.

Frequent issues that need to be addressed include:

- alignment with sub-categories defined in national statistics (e.g. Inventory Practice: Livestock population estimates in Croatia), and
- estimating number of days alive (see Inventory Practice: Estimating number of days alive).

Lack of activity data on livestock populations or sub-populations is common in many developing countries that might wish to adopt a Tier 2 approach. When collection of new data is required, agricultural or livestock censuses provide an opportunity to collect data on livestock populations and herd or animal characteristics. The FAO operates the World Programme on Agricultural Censuses, which supports countries to carry out census and provides methodological guidance, and the World Bank and FAO have produced a guidebook for designing the livestock component of household survey questionnaires (Zezza et al. 2016). Further practical guidance is provided by the Global Strategy to Improve Agricultural and Rural Statistics.

Further resources:

IPCC (2006) 2006 IPCC Guidelines Vol. 4 Chapter 10

FAO World Programme on Agricultural Censuses: http://www.fao.org/world-census-agriculture/en/

Global Strategy to Improve Agricultural and Rural Statistics http://gsars.org/en/tag/Livestock/

Zezza et al. 2016 Measuring the role of livestock in the household economy: a guidebook for designing household survey questionnaires. World Bank, Washington D.C. Available at: http://siteresources.worldbank.org/INTLSMS/Resources/3358986-1423600559701/Guidebook_2_Finaltext_web.pdf

Inventory practice: Estimating livestock population time series in Romania
Inventory practice: Livestock population estimates in Croatia
Inventory practice: Estimating number of days alive

3.2 Data sources for estimation of energy intake and methane emissions

The sub-sections that follow describe the types of data sources for specific parameters used by countries to compile data for estimation of energy intake and methane emissions from cattle. It summarizes data sources used in countries‘ initial Tier 2 inventory submissions as well as data sources used in the latest submissions, and describes the improvement pathways that countries have undergone (Text Box 3).

Text Box 3: Data sources for analysis of Tier 2 livestock inventories
By 2017, 63 out of the 197 Parties to the UNFCCC have used a Tier 2 approach in their livestock inventories. Submissions by developed (Annex 1) countries since 2003 are available on the UNFCCC inventory submission website. Submissions by developing countries are available on the websites for national communication and BUR submissions. These documents contain summaries of national inventories, and where publicly available, full national inventory reports from developing countries were also accessed. The transparency of national inventories by both developed and developing countries has improved over time, with more details on data sources available for later submissions than initial submissions. Thus, not all inventories reported data sources for all parameters used every year. About two thirds of Tier 2 applications used the IPCC model, while one third used a country-specific model. The IPCC model uses coefficients (Cf, Ca, C, Cp) and default values are provided in the IPCC guidelines. Countries that use the IPCC model always use the default values for these coefficients,[3] and no further analysis of data sources for these coefficients is given below. Country-specific approaches often do not use these coefficients, and some other variables in the IPCC model are also not estimated. As a result, for each of the parameters reviewed below, the total number of countries using each type of data source varies. Where the parameters listed were estimated but no data source is given, this is indicated by “no information“. Where parameters were not estimated in a country-specific model, this is indicated by “not estimated“.

Starting points for initial Tier 2 inventories: Lack of national data for some parameters is common when countries first adopt a Tier 2 approach. Some countries‘ initial Tier 2 inventory using the IPCC model was mainly populated by default factors or expert judgement (Country Case Studies Bulgaria, Estonia). A few countries were able to use mainly national data for most animal performance parameters in the IPCC model. For countries that use country-specific Tier 2 models, even though data availability can be considered in the design of the approach, IPCC default values, literature from other countries and expert judgement were also widely used in some initial Tier 2 inventories (e.g. Country case study New Zealand).

Improvements over time: Countries‘ inventory submissions reveal two main types of improvement over time:

(1) **improvements in data within the same model:** Each of the sections below describes examples of how countries have improved inventory estimates by changing data sources or data analysis methods to those that are more nationally appropriate or reliable. In

[3] For Cfi, some countries apply an adjustment for cold climate, as recommended in IPCC (2006). For Ca, many countries use an estimate of the proportion of the year on pasture to adjust the default values for Ca.

particular, some countries that started out with an IPCC model mainly populated by default values subsequently substituted several default values with national data sources (e.g. Country Case Study Estonia).

(2) **adjustments in the model:** Almost all countries that started using the IPCC model have continued to use that model. Refinements have been made to some components to account for national conditions (e.g. increasing use of concentrate in dairy feed) and to make use of existing knowledge and resources in the livestock sector (e.g. national feed tables, national energy balance models) (see e.g. Inventory Practice: Accounting for the effects of increased concentrate on gross energy intake and digestible energy; Inventory practice: Estimating digestibility using a country-specific approach in the UK). Some countries have adopted country-specific models after having used the IPCC model (e.g. Country Case Study UK). Countries using a country-specific approach have also improved and revised the methodological approaches or models over time (e.g. Country Case Studies Netherlands, Sweden, Japan).

Both incremental and more significant changes are often enabled by specific inventory processes, such as commissioned design of a country-specific approach, commissioned inventory review, inventory working groups to link research with inventory agencies and other institutional arrangements for continual improvement. These revisions are often enabled by advances in the livestock sector or other policy fields (e.g. nitrogen management), which are then used to improve the national GHG inventory (e.g. Country Case studies Denmark, Ireland, United Kingdom).

Further resources:
UNFCCC Website for National Inventory Submissions by developed countries:
https://unfccc.int/process/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories/submissions-of-annual-greenhouse-gas-inventories-for-2017

UNFCCC website for National Communication submissions by developing countries:
https://unfccc.int/process/transparency-and-reporting/reporting-and-review-under-convention/national-communications-0

UNFCCC website for Biennial Update Report submissions by developing countries:
https://unfccc.int/process/transparency-and-reporting/reporting-and-review-under-convention/biennial-update-reports-0

3.2.1 Animal weight estimates

For the 45 countries whose initial inventory reports indicated data sources for live weight estimates, expert judgement, literature from the country and commissioned studies (often as part of Tier 2 inventory design) accounted for about 50% of all data sources referred to (Table 7). About 30% of data sources were regularly reported statistics, agriculture or other government agencies or producer organizations. These sources include animal performance databases (Country Case Study Denmark, Inventory Practice: The role of cow recording systems in Norway's Tier 2 approach). When government agencies or producer organizations are cited as data sources, this is not always officially reported data derived from measurements, but may be similar to expert judgement. Four countries used calculation, equations or models to estimate animal weight. Over time, the number of countries reporting weights based on regularly reported statistical data, agriculture ministries or other government sources increased from 12 to 18, as did the number of countries using commissioned inventory studies to obtain data for this parameter.

Table 7: Data sources and methods for cattle animal weight estimates

	Initial Tier 2 NIR data sources	Latest Tier 2 NIR data sources
	n=45	n=45
Regularly reported statistics	3	4
Ministry of agriculture	7	11
Other government agency	2	3
Producer/industry organisation	3	1
Literature from own country	8	6
Commissioned study	4	7
IPCC default	3	1
Expert judgement	12	11
Estimated by calculation	3	3
Value from other country's inventory	1	1
Equation or model	1	2

How have countries improved their estimates of animal live weight over time?

Countries that started with no data: In their initial inventories, 3 countries (Estonia, Hungary, Croatia) used IPCC default data presented in the *IPCC 1996 Guidelines* in place of national values for animal weight. One country (Slovenia) used an equation to estimate dairy cow weight based on a relationship between milk yield and live weight and continues to use this method to date.[4] Expert judgement was also a common source of initial values for cattle weight. Among those countries that started with default values, Croatia later obtained a national dataset (2010-2014) on cattle weights as part of a thorough review to replace default values with national values in the inventory for enteric fermentation. Annual updates to this dataset are now used in updating the GHG inventory on an annual basis. Both Estonia and Hungary subsequently adopted methods whereby expert judgement and scientific literature or other reported data were used to estimate the average weight for each breed within the herd. This was then combined with population data from national breed registries (Estonia) or expert judgement on the proportion of breeds in the herd (Hungary) to estimate the weighted average animal weight. (See also Inventory Pratice: livestock characterization in Georgia). Portugal also filled missing data on animal weight with data from a 2004 published summary of breed registry data. Although the registries contained data on only 20% of the national breeding herd, it was assumed that much of the remaining 80% had derived from these registered breeding animals and would thus have similar characteristics. As a result of these methodological

[4] The relationship is: Weight (kg) = 418.8 + 0.0313 × [305 day milk yield (kg)]. However, a source for this equation is not given in the national GHG inventory.

choices, some countries' inventories do not reflect change in animal weight over time (e.g. Portugal). However, other countries have been able to estimate change in average weight on the basis of annually collected data or expert judgement on the changing breed composition of the herd (Estonia, Hungary).

Countries that started with estimated values or expert judgement: UK, Canada and Finland began with data sources that used estimation or expert judgement in the initial years. In some cases, initial expert judgements remained unchanged over several inventory submissions (e.g. Finland, dairy cattle in Canada). The UK began by applying an assumed 1% annual increase in animal weight to the initial value to produce a trend over time. Subsequently, all three of these countries adopted a method based on analysis of slaughter data. The UK and Finland now use annual slaughter data and a constant carcass ratio value (from literature or expert judgement) to estimate live weight (see Inventory Practice weight estimation using slaughter data in the UK). For beef cattle, Canada began with initial live weight estimates based on expert judgement, but subsequently estimated the trend in live weight by applying the trend in slaughter weight to the initial live weight estimate. With use of regularly reported slaughter data, weight estimates now vary year on year in Canada's inventory. Revisions to animal live weight estimates in New Zealand's inventory also illustrate how the best available data can be used in the absence of statistically representative national data (see Inventory Practice: Improving estimates of cattle weights in New Zealand).

Some other countries that began with expert judgement (e.g. as part of commissioned reviews) have continued to use expert judgement to update animal weight estimates. Lithuania uses expert judgement to update weight estimates annually, while the Czech Republic has updated estimates every few years during commissioned inventory reviews, which results in revision of historical estimates for the intervening years. Expert judgement can thus also be used to produce a time series and trend for animal weight.

Seasonal weight loss is common in many countries. IPCC (2000) suggested that seasonal weight loss or weight loss during early lacation could be addressed by separately estimating feed intake for the different seasons or lactation periods. IPCC (2006) suggested that reduced intakes and emissions associated with weight loss are largely balanced by increased intakes and emissions during the periods of gain in body weight. Very few countries' inventories explicitly account for weight loss. One example is Canada, whose initial Tier 2 inventory estimated net energy mobilized per kg of weight loss using Equations 4.4a and 4.4b from IPCC (2000).

Further resources:

IPCC Guidance:

IPCC (2000) IPCC GPG Ch 4 Agriculture

IPCC (2006) Volume 4 Ch. 10

Inventory case studies:

Inventory practice: Estimating cattle weights in the UK

Improving estimates of cattle weights in New Zealand

Resources for collection of new data:

GSARS resources on livestock production and productivity: http://gsars.org/en/tag/Livestock/

ICAR Beef cattle recording guidelines https://www.icar.org/Guidelines/03-Beef-Cattle-Recording.pdf

Wangchuk, K., Wangdi, J. and Mindu, M., 2018. Comparison and reliability of techniques to estimate live cattle body weight. *Journal of Applied Animal Research*, *46*(1), pp.349-352.

Goopy, J.P., Pelster, D.E., Onyango, A., Marshall, K. and Lukuyu, M., 2017. Simple and robust algorithms to estimate liveweight in African smallholder cattle. *Animal Production Science*.

3.2.2 Milk yield estimates

For the 40 countries whose initial inventory reports indicated data sources for milk yield estimates, regularly reported statistics were by far the most common source (Table 8). In the absence of regularly reported statistics, 8 countries used other types of report from the ministry of agriculture, other government agencies or producer organizations; 5 used literature values or values from other countries' inventories; and 4 estimated milk yield by expert judgment or calculation.

Table 8: Data sources and methods for milk yield estimates

	Initial NIR data sources	Latest NIR data sources
	n=45	n=34*
Regularly reported statistics	22	18
Ministry of agriculture	3	6
Other government agency	1	0
Producer/industry organisation	4	0
Literature from own country	3	0
Commissioned study	0	0
Expert judgement	3	0
Estimated by calculation	1	0
Value from other country's inventory	2	0
Interpolate	0	1
Equation or model	0	1

**2 countries report using a country-specific Tier 2 model that does not require milk yield as an input value: UKR, BLD. And data source was not mentioned in 16 countries' latest inventory submissions.*

Those countries that used literature values (e.g. Mongolia, Bolivia) mostly do not have a dairy cow emission factor time series that tracks change in emissions per head over time. In the absence of regularly reported milk yield data, Georgia estimates milk yield on the basis of expert judgement of milk yield by breed. A herd dynamics model then results in change in average milk yield reflecting the change breed structure (see Inventory Practice livestock characterization in Georgia).

Several countries have regularly reported milk yield data, but not a whole historical time series. For example, Croatia had data for 2008-2015 on milk yields, but not for 1990-2007. This earlier period was estimated by extrapolation from the existing data and expert judgement. Slovakia applied a linear function to existing data to extrapolate missing data for 1990-1996. Canada also used extrapolation methods to estimate a time series for milk yields based on a partial dataset (see Inventory practice: Estimating a time series for milk yields in Canada). Where a country lacks nationwide data on milk yields, estimates have been made on the basis of data for part of the herd in animal recording databases that are then extrapolated to the national herd (e.g. Inventory practice Estimating milk yields in Slovenia).

Countries use different types of regularly reported data for milk yield: some have sub-national reports of average milk yield per cow that are then aggregated to national level (e.g. Estonia prior to 2017). Other countries estimate per cow milk yields based on disaggregation of national total milk output data (see Inventory practice: estimating milk yield in Luxembourg).

Further resources:

IPCC Guidance:

IPCC (2006) Volume 4 Ch. 10

Inventory case studies:

Inventory practice: estimating milk yield in Luxembourg

Inventory practice: Estimating a time series for milk yields in Canada

Inventory practice Estimating milk yields in Slovenia

Resources for collection of new data:

GSARS resources on livestock production and productivity: http://gsars.org/en/tag/Livestock/

International Committee for Animal Recording (ICAR) Dairy Cattle Milk Recording Working Group https://www.icar.org/index.php/technical-bodies/working-groups/dairy-cattle-milk-recording-working-group/

Zezza, A., Federighi, G., Kalilou, A.A. and Hiernaux, P., 2016. Milking the data: Measuring milk off-take in extensive livestock systems. Experimental evidence from Niger. *Food policy*, *59*, pp.174-186

3.2.3 Proportion of cows giving birth

Relatively few countries explicitly report in their GHG inventory the source of data for the proportion of cows giving birth in a year (Table 9). Official and industry sources account for about half the total sources referred to in NIRs. Expert judgement and literature from the country are also used by about one third of countries. When data is lacking, alternative estimation methods are used, including:

IPCC default values: Greece began by using the IPCC default (0.9 for western Europe, IPCC 1996 reference manual table A-1) in its initial Tier 2 national inventory, and continues to use that value in its current inventory.

Calculation: Calculation methods vary, depending on the available data from which the proportion giving birth is estimated.

- Ukraine's initial Tier 2 model calculated the proportion pregnant on the basis of the annual number of cows reported in national statistics as calving and inseminated cows, and the number of calves at the beginning of the year.
- Namibia estimates the proportion pregnant on the basis of the estimated number of young females in the population.
- Canada's initial Tier 2 inventory used the equation: Percent cows pregnant = (gestation length/calving interval X 100) – percent cows culled due to reproductive failure.

Table 9: Data sources and methods for estimates of % giving birth

	Initial NIR data source	Latest NIR data source
	n=12	n=25
IPCC default	1	1
Regularly reported statistics	3	5
Ministry of agriculture	3	3
Other government agency	0	2
Producer/industry organisation	4	2
Literature from own country	2	1
Commissioned study	0	1
Expert judgement	5	6
Estimated by calculation	1	2
Value from other country's inventory	1	1

Further resources:

IPCC Guidance:

IPCC (2006) Volume 4 Ch. 10

Resources for collection of new data:

GSARS resources on livestock production and productivity: http://gsars.org/en/tag/Livestock/

Zezza et al. 2016 Measuring the role of livestock in the household economy: a guidebook for designing household survey questionnaires. World Bank, Washington D.C. Available at: http://siteresources.worldbank.org/INTLSMS/Resources/3358986-1423600559701/Guidebook_2_Finaltext_web.pdf

3.2.4 Feed digestibility estimates

In initial Tier 2 submissions, estimates of feed digestibility came from ministries of agriculture or other government agencies and producer organizations in 7 countries, although information provided by these agencies are are sometimes similar to expert judgements and may not all be based on direct measurements of feed digestibility (Table 10). Literature from the country, mostly official feed tables, was used in 5 countries. Countries, such as Poland, that commissioned a study for elaboration of their whole Tier2 approach, also obtained national data on feed digestibility through this commissioned study.

In the absence of country-specific data, about half of countries used the appropriate IPCC default value for feed digestibility, while expert judgement (5) was also common. Moldova, for example, used expert judgement to reconstruct a time series for change in average digestibility in different historical periods (Inventory Practice: Reconstructing a time series for feed digestibility in Moldova). Literature from other countries was also used (e.g. Slovenia used data from German feed tables; Belgium used Dutch digestibility data) in the absence of national data.

Table 10: Data sources for feed digestibility estimates

	Initial NIR data sources	Latest NIR data sources
	n=35	n=35
Regularly reported statistics	0	0
Ministry of agriculture	3	4
Other government agency	1	2
Producer/industry organisation	2	0
Literature from own country	5	12
Commissioned study	1	6
Literature from other country	3	1
IPCC default	16	7
Expert judgement	6	6
Estimated by calculation	0	1
Equation or model	0	5

Improvement pathways for feed digestibility estimates:

Countries that started with no national data: More than half of the 13 countries that began by using IPCC default values for digestibility subsequently used other data sources to identify country-specific values. Two countries (Bulgaria and Estonia) used scientific publications, and a third (Latvia) commissioned a study that was then combined with expert judgement on typical diets to estimate feed digestibility for the national inventory (Inventory Practice: Improving feed digestibility estimates in Latvia). Four countries (Portugal, UK, Hungary, Slovenia) identified country-specific values on the basis of national feed tables. The particular ways in which these feed tables were used varied according to the way in which they relate feed composition and digestibility to livestock performance parameters (see Country case study UK; Country Case Study Sweden; Inventory practice: Use of feed tables for estimating gross energy in Lithuania; Inventory practice: Use of national feeding standards to estimate net energy requirements in Hungary).

Continual improvement in feed digestibility data: Several countries that did have national data to start with also improved or continually updated data sources over time. The USA provides an example of how annual surveys of small numbers of animal nutrition experts across the country are used to produce updated estimates of feed digestibility (Inventory Practice: Expert judgement updates feed digestibility estimates in the USA).

Improvements through refinement of the IPCC model: A few countries have made particular refinements of the IPCC Tier 2 model in order to improve estimates of digestibility and to improve estimates of Ym in view of the composition of feed. With an increasing proportion of concentrate in dairy cattle feed, Slovenia has adopted the results of research by INRA that established a relationship between organic matter digestibility (dOM) and net energy for lactation (see Inventory Practice: Accounting for the effects of increased concentrate use of gross energy intake and digestible energy). The UK also changed from using IPCC default values to expert judgement and later used a country-specific energy balance model to improve its estimate of feed digestibility for dairy cattle (Inventory practice: Estimating digestibility using a country-specific approach in the UK).

Further resources:

IPCC Guidance:

IPCC (2006) Volume 4 Ch. 10

Inventory case studies:

Inventory Practice: Reconstructing a time series for feed digestibility in Moldova

Inventory Practice: Improving feed digestibility estimates in Latvia

Inventory practice: Use of feed tables for estimating gross energy in Lithuania

Inventory practice: Use of national feeding standards to estimate net energy requirements in Hungary

Inventory Practice: Accounting for the effects of increased concentrate use of gross energy intake and digestible energy

Inventory practice: Estimating digestibility using a country-specific approach in the UK

Inventory Practice: Expert judgement updates feed digestibility estimates in the USA

Resources for collection of new data:

Feedipedia: An online encyclopedia of animal feeds https://www.feedipedia.org/

Madsen, J., Hvelplund, T. and Weisbjerg, M.R., 1997. Appropriate methods for the evaluation of tropical feeds for ruminants. *Animal Feed Science and Technology*, *69*(1-3), pp.53-66.

FAO (2004) Assessing Quality and Safety of Animal Feeds. Available at http://www.fao.org/3/a-y5159e.pdf

3.3 Data sources for estimating methane yield (Ym)

In initial Tier 2 inventories most countries used IPCC default values for the methane conversion factor (Ym), and almost 70% of countries continue to use default values in their most recent inventory submissions. Country-specific values have been obtained from government research agencies (1 in Italy) and published literature (3), and in the absence of national data, scientific publications from other countries, expert judgement and values in other countries' inventories have also been used (e.g. Hungary cited values in the Swiss inventory report). In subsequent submissions, results from commissioned direct measurement studies were cited as a data source by 2 countries (Belgium and France). More commonly, scientific studies are used to validate the model used in the national GHG inventory to predict the methane conversion factor (5 countries).

The models and equations used range from the simple to the complex. Croatia recently began to estimate Ym using an equation from an FAO publication by Hristov (i.e. Ym=9.75 -0.05*DE%) (Hristov et al. 2013). Norway's inventory estimates Ym for dairy cattle using an equation relating Ym to milk yield and the proportion of feed concentrate in the diet, data that are available from a cattle recording database (Inventory Practice: The role of cow recording systems in Norway's Tier 2 approach). Denmark, Colombia and the USA, on the other hand, estimate Ym using more complex models based on feed chemical composition, while the model used in The Netherlands also includes more specific modelling of rumen processes.

Modelling livestock emissions is a dynamic field and the models used vary considerably (Hiristov et al. 2013, Hristov et al. 2018, Niu et al. 2018). The models used have in each case been validated against individual cow measurements. While some models have been developed specifically for GHG inventories, most were developed for feed evaluation and provision of farm advisory services. The availability of increasing data for validation and improvement of the models is often therefore driven by progress in livestock research rather than specific inventory needs. Commissioned inventory reviews are one way in which inventories can capitalise on the increasing knowledge in the livestock sector.

Table 11: Data sources for methane conversion rate (Ym) estimates

	Initial NIR data sources	Latest NIR data sources
	n=40	n=43
IPCC default	28	29
Other government agency	1	0
Literature from own country	3	3
Commissioned study	0	2
Expert judgement	2	1
Estimated by calculation	1	1
Value from other country's inventory	0	1

Equation or model	4	5
Literature from other country	0	1

Further resources:

IPCC Guidance

IPCC (2006) Volume 4 Ch. 10

Reviews:

Hristov, A. et al. 2013. Mitigation of greenhouse gas emissions in livestock production – A review of technical options for non-CO2 emissions. FAO Animal Production and Health Paper No. 177. FAO, Rome, Italy. Available at: http://www.fao.org/docrep/018/i3288e/i3288e.pdf

Hristov, A. et al. 2018. *Symposium review:* Uncertainties in enteric methane inventories, measurement techniques, and prediction models. Journal of dairy sciences. Available at: https://doi.org/10.3168/jds.2017-13536

Niu, M. et al., 2018. Prediction of enteric methane production, yield, and intensity in dairy cattle using an intercontinental database. *Global change biology*. Available at: DOI: 10.1111/gcb.14094

Resources for collection of new data:

Berndt, A. et al. 2014. Guidelines for use of sulphur hexafluoride (SF 6) tracer technique to measure enteric methane emissions from ruminants. Pages 166. M. G. Lambert, ed. New Zealand Agricultural Greenhouse Gas Research Centre, New Zealand. Available at: https://globalresearchalliance.org/wp-content/uploads/2018/02/SF6-Tracer-Technique-Guidelines_April-2014.pdf

Pinares, C. and Waghorn, G. (eds.) 2014. Technical Manual on Respiration Chamber Designs. Ministry of Agriculture and Forestry, New Zealand. Available at: https://www.globalresearchalliance.org/wp-content/uploads/2012/03/GRA-MAN-Facility-BestPract-2012-FINAL.pdf

3.4 Data sources for estimating manure management methane

Most countries that use a Tier 2 approach for enteric fermentation from cattle also use a Tier 2 approach to estimate methane emissions from manure management. Of these 57 countries, 48 use the IPCC model as set out in the IPCC guidelines. Three countries follow that model, but instead of calculating the amount of volatile solids input into manure management systems, volumes are estimated using normative standards for manure management. Six countries use country-specific models of methane emissions from manure management. For example, Japan has a considerable body of direct measurements of methane emission factors, which it uses alongside other data sources in its inventory (see Inventory Practice: Choice of emission factor for manure management in Japan).

3.4.1 Data on methane production potential and methane conversion factors

The IPCC model includes a parameter for the maximum methane production capacity (Bo) and a parameter for the methane conversion factor (MCF). The vast majority of countries that reported a data source use the IPCC default factor for both parameters (Table 12). Some countries inventories used values from published literature or commissioned studies. These reviews often included international literature and some countries used values from studies in other countries. Where the model used requires data on ash content of manure, about 70% of countries used the IPCC default values. Other data sources included published literature from the same or another country, commissioned reviews and estimation using a model (e.g. national ammonia or nitrogen balance model).

Table 12: Data sources for methane manure management parameters Bo and MCF

	Maximum methane-producing capacity of manure (Bo)		Methane conversion factor (MCF)	
	Initial Tier 2 inventory	Latest Tier 2 inventory	Initial Tier 2 inventory	Latest Tier 2 inventory
No or unclear info	22	15	19	15
IPCC default value	26	35	30	36
Literature from own country	1	5	3	5
Commissioned study	1	3	1	4
Expert judgement				1
Estimate by calculation			1	1
Literature from other country	1	1	1	3

3.4.2 Data on manure management systems

Sources of data for manure management systems are quite diverse, and many countries have improved their estimates over time. Among countries reporting data sources, the most common data sources were expert judgement, data provided by agricultural, statistics or other government agencies, and commissioned studies. In many cases, surveys conducted by government agencies or researchers were irregular (e.g. decadeal census, biannual or one-off surveys), and several countries use interpolation between survey dates to construct a consistent time series. Several countries use housing surveys together wiht expert judgement to estimate the manure management systems used in different types of housing system or farm. In addition, manure management categories reported in official surveys often differ from the categories used in the IPCC, so expert judgement is applied to convert available data into a times series consistent with IPCC categories.

Table 13: Data sources for the allocation of manure to manure management systems

	Initial NIR data sources	Latest NIR data sources
No or unclear info	20	21
IPCC default value	4	1
Statistics agencies	2	4
Agriculture agencies	6	10

Other government agency	4	1
Literature from own country	4	8
Commissioned study	5	6
Expert judgement	10	14
Interpolate	0	8
Literature from other country	1	1

Where data is unavailable, methods used to collect data include structured surveys to elicit expert judgement (Inventory Practice: Structured elicitation of expert judgement on manure management systems in Canada). More commonly, however, a variety of sources are drawn upon to provide the best available estimate of the distribution of manure in different management systems (Inventory Practice: Characterization of manure management systems in Finland). Some countries have managed to improve the availability of data on manure management systems by incorporating related questions in regular surveys (Country Case Study: Austria, Country Case Study: Bulgaria).

Further resources:

IPCC (2006) Vol 4 ch 10

Manure Management Kiosk manurekiosk.info/

Inventory practices:

Inventory Practice: Structured elicitation of expert judgement on manure management systems in Canada

Inventory Practice: Characterization of manure management systems in Finland

Inventory Practice: Choice of emission factor for manure management in Japan

4 IMPLEMENTING QA/QC PROCEDURES

Quality assurance and quality control (QA/QC) are important components of IPCC good practice guidance. General guidance is given in IPCC 2000 and 2006, and specific guidance for QA/QC of livestock inventories is given in IPCC (2006, vol 4 ch. 10, section 10.5.6). The reporting formats for developed country GHG inventories ensure that all developed countries report activities conducted for category-specific QA/QC and verification.

Text Box 4: IPCC (2006) definitions of QA/QC 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 objectives (data quality objectives, see Section 6.5, 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: IPCC (2006) Vol 1 Ch 6

Livestock components of national inventories are subject to general QA/QC activities that are applied to the whole inventory (referred to in IPCC 2000 as Tier 1 activities), while source-specific QA/QC is referred to as Tier 2 activities. Source-specific QA/QC activities are generally applied to both activity data and emission factors. For livestock emission sources, common QA/QC methods include the following:

Activity data:

- Comparison between alternative domestic data sources (e.g. comparing 10-year livestock population census data with 2-3 year farm survey data)
- Comparison of national with FAO or other databases (Inventory practice: Estimating livestock population time series in Romania)

Emission factors:

- Comparison with neighbouring countries and IPCC default values (Inventory practice: Verification of emission factors in South Africa; Inventory practice: QA and verification in Australia's GHG inventory)
- Comparison with published research data (Inventory practice: QA and verification in Australia's GHG inventory)
- Analysis of IEF trend over time (Inventory practice: Verification of Denmark's inventory inputs and results)
- Conversion of estimated gross energy to kg feed and comparison with animal weight (Inventory practice: QA and verification in Australia's GHG inventory)

A variety of tools and institutional arrangements for inventory compilation and review are used in QA/QC activities, including:

- Internal data checks (Inventory practice: QA/QC in Poland's inventory, Inventory practice: QA/QC in Norway's inventory, Inventory practice: QA/QC in The Netherlands) often facilitated by data management systems
- Commissioned reviews (Country case studies New Zealand, Sweden), and
- External reviews.

Further resources:

IPCC (2000) Quality assurance and quality control. https://www.ipcc-nggip.iges.or.jp/public/gp/english/8_QA-QC.pdf

IPCC (2006) Quality assurance, quality control and verification. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/1_Volume1/V1_6_Ch6_QA_QC.pdf

IPCC (2006) Emissions from livestock and manure management https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf

Inventory practice:

Inventory practice: QA/QC in Poland's inventory

Inventory practice: QA/QC in Norway's inventory

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5 ASSESSING THE UNCERTAINTY OF A TIER 2 INVENTORY

Analysis of uncertainty in an inventory can serve to guide decisions on choice of methodological tier and prioritise national efforts for inventory improvement (IPCC 2006 Vol 1, Ch 3). The IPCC provides general guidance on uncertainty assessment in GHG inventories (IPCC 2000, IPCC 2006 Vol 1 Ch 3). For livestock GHG sources, additional general guidance is given in IPCC (2006 Vol 4 Ch 10). The IPCC recommends that category-specific estimates of uncertainty at the 95% confidence interval are developed for inventory categories. Ideally, these uncertainty estimates are developed using category-specific data, but in the absence of such estimates default values for uncertainty are provided. For example, enteric fermentation emission factors estimated using a Tier 1 approach are assumed to have an uncertainty range of between ±30% and ±50%, while a Tier 2 emission factors are assumed to have an uncertainty range of ±20% IPCC (2006 Vol 4 Ch 10). Beyond the use of IPCC default values, possible methods for uncertainty assessment include model validation, inter-model comparisons, error propagation, Monte Carlo simulation and expert judgement (IPCC 2006 Vol 1 Ch 3).

Previous analysis of developing countries' livestock GHG inventories found that only about one third of countries reported any assessment of uncertainty in their national inventory (Wilkes et al. 2017). Of the 63 countries that use a Tier 2 approach in their livestock inventory, 7 countries did not report results of uncertainty assessment. Of the 56 countries that did, 49 reported a quantitative estimate of activity data uncertainty. Data sources used to derive activity data uncertainty estimates included reports of error ranges from statistical agencies, expert judgement and reference to values in other countries' inventories. Six countries reported only an estimate for total uncertainty of livestock emissions (e.g. where Monte Carlo simulation had been applied), and 50 reported a specific estimate of emission factor uncertainty. Of these 50 countries, about 20 quantified emission factor uncertainty using the IPCC default values. Other methods used included error propagation, Monte Carlo analysis and expert judgement.

Text Box 5: What difference does using a Tier 2 approach make to uncertainty in the inventory?

***Comparison of uncertainty when using Tier 1 and Tier 2 approaches*:** 20 countries reported uncertainty of enteric fermentation or sub-categories (e.g. cattle or 'dairy cattle') emission estimates for earlier inventories using a Tier 1 approach and the initial Tier 2 inventory. Reported uncertainty decreased for 9 countries, remained the same for 8 countries and increased for 3 countries. In all cases, IPCC default values were used to estimate uncertainty. Whether adopting a Tier 2 approach reduces inventory uncertainty thus depends on whether data sources and methods for uncertainty estimation also change.

Trends in uncertainty of Tier 2 estimates over time: 36 countries reported uncertainty estimates for both the year of initial adoption of Tier 2 and the latest inventory submission. Reported uncertainty decreased for 20 countries, remained the same for 10 countries, and increased for 6 countries. All 6 countries reporting an increase in UNC(TOT) also changed the method used for uncertainty assessment between the two submissions assessed, replacing default uncertainty estimates with the results of error propagation or Monte Carlo analysis. The reported uncertainty values are therefore not strictly comparable.

These findings suggest that the effect of adopting Tier 2 on uncertainty of inventory estimates depends as much on improvement in methods for estimating and reporting uncertainty as it does on the benefits for uncertainty reduction of adopting a Tier 2 approach.

Analysis of livestock inventory uncertainty is provided in national inventory reports from Canada, Finland, New Zealand, and the UK. These examples show how uncertainty analysis can be used to identify the main parameters that are sources of uncertainty in a given inventory year, or in the trend in an inventory over time (Inventory practice: Analysis of uncertainty in Canada's livestock inventory). They can also help inform decisions about the adoption of Tier 2 approaches (Inventory practice: Assessing sources of uncertainty in Finland's livestock inventory), priorities for further research (Inventory practice: Uncertainty analysis to prioritize further research in New Zealand) and identify regional focuses within a country for reduction in uncertainty levels (Inventory practice: Assessing sources of uncertainty in the livestock inventory of the United Kingdom).

Further resources:

IPCC Guidance:

IPCC 2006 Vol 1 Ch 3

IPCC 2006, Vol 4 Ch 10

Inventory practice case studies:

Inventory practice: Analysis of uncertainty in Canada's livestock inventory

Inventory practice: Assessing sources of uncertainty in Finland's livestock inventory

Inventory practice: Uncertainty analysis to prioritize further research in New Zealand)

Inventory practice: Assessing sources of uncertainty in the livestock inventory of the United Kingdom

6 CONTINUAL IMPROVEMENT OF TIER 2 INVENTORIES

The UNFCCC requires that national GHG inventories are transparent, consistent, comparable, complete and accurate, and submitted in a timely manner. For developed countries, inventory compilation should follow guidance in IPCC (2006). Guidelines for the preparation of developing countries' national communications recommend that developing countries should use the *Revised 1996 IPCC Guidelines for National GHG Inventories* (IPCC 1996) for estimating and reporting their national GHG inventories, and *IPCC GPG and Uncertainty Management in National GHG Inventories* (IPCC 2000), "taking into account the need to improve transparency, consistency, comparability, completeness and accuracy in inventories" (Decision 17/CP.8). In addition to these principles for inventory compilation, countries may also intend that national GHG inventories serve national policy objectives by reporting a precise trend in emissions over time (Wilkes et al. 2017). Continual improvement refers to the process of ensuring that national GHG inventories deliver these intended outcomes.

General guidance on making inventoryimprovement plans is given on improvement planning for the whole national inventory and for specific sources in capacity building materials produced by US EPA and UNFCCC (see Further Resources). Inputs to the elaboration of an inventory improvement plan for livestock emission sources may come from a variety of other inventory compilation activities – such as key source analysis, documentation of data sources and methodologies, QA/QC activities or uncertainty assessment – and from different sources depending on who is involved in the inventory process and how.

Methods such as sensitivity analysis, key category analysis and uncertainty analysis can contribute to identifying priorities for improvement. An example of sensitivity analysis is provided in Inventory practice: Sensitivity analysis to prioritize improvements in Senegal. Inventory practice: Regional characterization of dairy cattle in New Zealand shows how using different data sources and methods to estimate the same emission source can inform decisions that improve the accuracy of inventory estimates. Beyond specific analytical methods, many countries use a variety of approaches to enable continual improvement, including

- quality meetings between the inventory unit and other participating organisations (Inventory practice: Institutional arrangements for compilation of the UK's livestock emissions inventory)
- external peer reviews and audits[5]
- commissioned studies, and
- advisory panels (Inventory Practice: New Zealand's agriculture inventory advisory panel).

In addition to preparation of specific improvement plan, continual improvement in livestock GHG inventories can also be assisted through linkages between inventory improvement and national research programmes (Inventory Practice: UK's GHG R&D Platform supports inventory improvements). Many other countries have also commissioned research on specific inventory needs, as shown in the number of countries reporting commissioned research as a source of data in Chapter 3.

Further resources:

US EPA national GHG inventory capacity building
https://www3.epa.gov/climatechange/Downloads/EPAactivities/TMPzrk3zr.htm#Approach

UNFCCC (2016) Preparing a National Inventory Improvement Plan (NIIP) Available at:
https://unfccc.int/files/national_reports/non-annex_i_natcom/cge/application/pdf/6_-_improvement_plan_rev1.pptx.pdf

[5] E.g. https://www.anao.gov.au/work/performance-audit/accounting-reporting-australias-greenhouse-gas-emissions-estimates

Inventory practices:

Inventory practice: Sensitivity analysis to prioritize improvements in Senegal

Inventory Practice: New Zealand's agriculture inventory advisory panel

Inventory practice: Institutional arrangements for compilation of the UK's livestock emissions inventory

Inventory Practice: UK's GHG R&D Platform supports inventory improvements

ANNEX 1: COUNTRY INVENTORY CASE STUDIES

List of country inventory case studies:

Country inventory case study: Austria

Overview of Austria's current Tier 2 approach

Livestock types	Tier used for enteric fermentation (CH_4)	Year adopted*	Tier used for manure management (CH_4)	Year adopted*
Dairy cattle	T2	2003	T2	2003
Non-dairy cattle	T2	2003	T2	2003
Sheep	T1	-	T1	-
Pigs	-	-	T2	2003
Other	T1	-	T1	-

*Year refers to the year of NIR submission

Livestock categorization method:

Dairy cattle	Non-dairy cattle	Swine
1 category	8 categories defined by: Age, physiological status, production system (organic / non-organic)	3 categories: young & fattening pigs >20 kg; breeding sows > 50 kg; piglets <20 kg.

Enteric fermentation

Approach used: Intake-based estimate of gross energy

Why was this approach adopted? Before 2003, livestock emissions were estimated using the CORINAIR system for GHG inventories. Because this model is not consistent with IPCC GPG requirement to use a higher Tier approach for key sources, Austria developed a Tier 2 approach in NIR 2003. Available research on nitrogen-flows in livestock systems was used for key sources (i.e. cattle).

Description of approach: Austria's initial Tier 2 approach was based on research on nitrogen flows in livestock production systems that had been conducted as part of Austria's compliance with the European Commission's Nitrates Directive, which limits nitrogen application rates on agricultural land. An EC methodology was applied to estimate the N content of manure based on dietary N intake, N content of livestock products and gaseous N losses. DMI was estimated on the basis of prior research that used 20-year feeding experiment data to predict feed intake on the basis of nutritional (forage quality and composition, concentrate level) and animal factors (milk yield, live weight, stage of lactation, breed). In the initial version of the N-flow model, crude protein was the main nutritional content of the ration considered. Crude protein content in different diets required to achieve different levels of milk yield enabled estimation of DMI of those diets, and DMI is then converted to GE. The national GHG inventory uses data from statistics agencies on milk yield and live weight to estimate GE. GE is then converted to methane emissions using the IPCC equation (EF=GE*Ym/55.65).

Implementation of the approach:

For dairy cattle, GE is estimated from annual statistical data on milk yield. The EF thus changes with fluctuation between years in average milk yield, which is assumed to reflect change in the underlying diet.

Table A: Relationship between energy intake and milk yield for dairy cattle in Austria

Milk yield	3500	4000	4500	5000
GE (MJ GE day^{-1})	214.96	227.63	240.22	252.75

Source: Austrial NIR 2017

For non-dairy cattle, diet varies depending on whether they are in organic or non-organic production systems. Typical diets in organic and non-organic systems were characterised for different classes of non-dairy cattle.

Expert opinion suggests that typical diets did not change over time, thus GE per animal remains constant in the time series. However, the proportion of cattle in organic and non-organic systems does change. Annual activity data on numbers of cattle of different classes in each production system are used. Thus, the implied emission factor changes year to year, depending on the structure of the cattle population in different production systems.

Table B: Typical diets and gross energy of non-dairy cattle in conventional and organic production systems in Austria

		Suckling cows	Cattle <1 year	Cattle 1-2 years	Cattle >2 years
Conventional	Live weight	600 kg	210 kg	530 kg	600 kg
	diet	50% green feed 20% hay 30% grass silage	15% green feed 20% hay 30% grass silage 35% maize silage	20% green feed 15% hay 30% grass silage 35% maize silage	40% green feed 20% hay 30% grass silage 10% maize silage
	GEI (MJ GE day^{-1})	191.56	84.36	166.96	163.44
Organic		Suckling cows	Cattle <1 year	Cattle 1-2 years	Cattle >2 years
	Live weight	600 kg	190 kg	480 kg	580 kg
	diet	50% green feed 20% hay 30% grass silage	355% green feed 20% hay 45% grass silage	40% green feed 15% hay 45% grass silage	40% green feed 15% hay 45% grass silage
	GEI (MJ GE day^{-1})	191.56	72.06	151.14	159.93

Source: Austrial NIR 2017

Inventory improvements:

	Improvement	Year*
Activity data	-	
Livestock characterization	-	
Emission factors	Re-estimation of milk yield – GE relationship	2007
	Revision of GE estimates for non-dairy cattle	2010
	Adoption of IPCC 2006 GL Ym default value	2015
Uncertainty estimation	Replaced UNC_{AD} literature value with value based on review of statistical data	2016

*Year refers to the year of NIR submission

Re-estimation of milk yield – GE relationship (2007): 2005 and 2006 inventory reviews suggested improving the relationship between GE and milk yield. The main improvement in the inventory method was a re-estimation of the milk yield-GE relationship for dairy cattle. This was based on research publication (Gruber & Pötsch 2006) and included in the 2007 NIR. The research reviewed actual feed rations based on expert opinion from farm advisors, and forage quality based on field studies in representative grassland and dairy farm areas. The re-estimation led to higher EFs because the revised model considered more indicators of forage composition and quality than the original model, which considered protein only.

Revision of GE estimates for non-dairy cattle: In NIR 2010, new studies on suckler calf growth suggested higher growth than previously assumed and thus higher milk yields to support calf growth. This resulted in changes in the estimated GE per animal in non-dairy cattle systems.

Adoption of IPCC 2006 GL Ym value: Prior to NIR 2015, the IPCC 1996 Ym value of 0.60 was used. In 2014, work focused on revising the agricultural model according to the IPCC 2006 GL, which was reviewed by external Austrian agricultural experts.

Manure management (Methane)

Approach used: IPCC approach (T2 for cattle and swine), T1 for other livestock.

Description of approach: The Austrian Tier 2 approach uses the IPCC Tier 2 model for manure management.

Implementation of the approach:

- Activity data are taken from national statistics.
- N excretion rates for the different types of cattle were derived from the model used to estimate GE for enteric fermentation (see above). For non-dairy cattle, VS excretion rates are converted using country specific research on GE intake, digestibility and ash content. For swine, there is no data on performance, and VS excretion rates of swine were kept constant for the whole time series.
- Values for Bo and MCF initially used IPCC default values, but these were later updated using national research.
- The fraction of manure handled in different management systems initially used data from an academic study. These were later updated using a new study, and a combination of extrapolation and expert opinion were used to recalculate the time series for each type of MS.

Inventory improvements:

	Improvement	Year*
Activity data	-	
Manure management systems	New data on distribution of manure in different management systems	2010
	Including biogas in management systems	2013
Emission factors	Re-estimation of milk yield – N excretion relationship	2007
	Country-specific values for MCF	2010
	Estimation and re-estimation of biogas MCF	2013
Uncertainty estimation	Replaced UNC_{AD} literature value with value based on review of statistical data	2016

*Year refers to the year of NIR submission

Re-estimation of N excretion rates: The research used to re-estimate GE values for enteric fermentation in NIR 2007 (Gruber and Pötsch 2006) was also used to re-estimate N and VS excretion values for different types of cattle. A time series for VS was generated based on the times series for milk yield and the distribution of livestock between production systems.

Improvements in manure management system (MMS) data: Austria's initial inventories noted the lack of national statistics on MMS. NIRs 2003-2009 used data from an academic publication reporting a survey conducted in 1989-1992. Due to lack of alternative data, this data was applied to the whole reporting period 1990-2001. Inventory review reports in 2006 and 2008 noted that the distribution of housing and storage systems has undergone major changes. In 2008, the inventory agency commissioned a review of the estimation method, and a nationally representative survey of MMS conducted in 2005 by a national research project was identified (Amon et al. 2007). To use the survey data on MMS in the NIR 2010, a plausible time series using the earlier survey and new survey data was created using expert opinion for years prior to 2005, and using linear extrapolation for years after 2005. The survey also provided improved information on the timing of storage, which could be used together with measurements of emission factors (see below) to improve emission estimates.

Country-specific values for MCF for liquid systems: The agriculture and education ministries had funded a 3-year measurement campaign on emissions from manure stores. Results were published in peer reviewed publications,[6] and were used for MCF values for liquid manure systems in NIR 2010.

Adding biogas storage to the MMS and MCF data: Inventory review in 2013 recommended to include consideration of biogas as a management method. This was done in NIR 2015 using data from different sources for different years. Initially, methane losses were not considered. A centralized expert review recommended to consider this, and the MCF for biogas storage was revised in NIR 2016.

Uncertainty management

Uncertainty of activity data: Prior to NIR 2016, UNC_{AD} was estimated on the basis of a literature value. In 2016, livestock statistics were reviewed. Uncertainties were derived by analysing official Austrian livestock numbers published in June and December each year. Comparing these two data sets the standard deviation was calculated. As a conservative approach the doubled standard deviation was taken, leading to uncertainties for dairy cattle of 2%, for non-dairy cattle of 1% and for swine of 4%.

Uncertainty of emission factors: In the 2003 inventory, uncertainties for enteric fermentation were estimated using Monte Carlo simulation. Assuming a normal probability distribution, the calculated standard deviation is 4%. This indicates there is a 95 % probability that CH_4 emissions are between +/- 2 standard deviations, i.e. between 153 Gg and 178 Gg in the year 1990 and between 138 Gg and 162 Gg in the year 2001.

The Monte Carlo uncertainty method used has the advantage, compared to the default propagation method, that it produces better results if the uncertainty is in a higher range [Winiwarter & Orthofer, 2000]. Uncertainties that were taken into account for calculations of the total uncertainty include:

- Gross Energy Intake (GE): +/- 20% (estimated by expert judgement of Dr. Amon)
- Methane Conversion Factor (Ym) cattle: +/- 8.3% [IPCC Guidelines, 1997]
- Livestock: (Source: Statistic Austria; sample survey –) statistical accuracy 95%
- Share of organic farming: +/- 10% (estimated by expert judgement)
- EF for Sheep, Swine, Horses, Goats (IPCC default values): +/- 30% [IPCC Guidelines, 1997]
- The emission factors for the "Tier 2" method are determined by the uncertainty of the gross energy intake (GE) and the CH_4 conversion rates (Ym). The uncertainty was estimated to be to be about +/- 20% (Amon et al. 2002).

[6] AMON et al. 2002a, 2006, 2007a

Further resources

Austria National Inventory Reports 2003, 2010, 2016, 2017.

Amon, B. and Hörtenhuber, S. (2010): Revision of Austria's National Greenhouse Gas Inventory, Sector Agriculture. Final Report. Division of Agricultural Engineering (DAE) of the Department for Sustainable Agricultural Systems of the University of Natural Resources and Applied Life Sciences (BOKU), study on behalf of Umweltbundesamt GmbH. Wien. (unpublished)

Amon, B., Hopfner-Sixt, K. and Amon, T. (2002): Emission Inventory for the Agricultural Sector in Austria – Manure Management, Institute of Agricultural, Environmental and Energy Engineering (BOKU – University of Agriculture, Vienna), July 2002.

Amon, B., Kryvoruchkp, V. and Amon, T. (2006). Influence of different levels of covering on greenhouse gas and ammonia emissions from slurry stores. International Congress Series (ICS) No 1293 "2nd International Conference on Greenhouse Gases and Animal Agriculture."

Amon, B., Fröhlich, M., Weissensteiner, R. et al. (2007). Tierhaltung und Wirtschaftsdüngermanagement in Österreich. Studie im Auftrag des Bundesministeriums für Landund Forstwirtschaft, Umwelt- und Wasserwirtschaft, Wien.

Gruber & Pötsch 2006 Calculation of nitrogen excretion of dairy cows in Austria. Die Bodenkultur, 2006, Vol. 57, Heft 1–4, Vienna

Country inventory case study: Bulgaria

Overview of Bulgaria's current Tier 2 approach

Methane from enteric fermentation and N_2O from animal sources have consistently been identified as key sources in Bulgaria's GHG inventory. Together, cattle and sheep have accounted for 80-90% of enteric fermentation emissions in each inventory year since the late 1980s. Bulgaria began to use the IPCC Tier 2 approach for cattle in 2010, and for sheep in 2011. Inventories since 2003 have reported using a Tier 2 approach for methane emissions manure management, but no technical description of the approach used is given in the inventory reports.

Table 1: Overview of Tiers used for livestock methane emissions in Bulgaria's national GHG inventories

Livestock types	Tier used for enteric fermentation (CH_4)	Year adopted*	Tier used for manure management (CH_4)	Year adopted*
Dairy cattle	T2	2010	T2	2003
Non-dairy cattle	T2	2010	T2	2003
Sheep	T2	2011	T1	-
Pigs	T1	-	T2	2003
Other	T1	-	T1	-

*Year refers to the year of NIR submission

Enteric fermentation

Description of approach: Bulgaria implements the IPCC Tier 2 model for both cattle and sheep. The approach estimates daily gross energy (GE) intake on the basis of animal performance, management practices and environmental factors. GE is converted to methane using a methane conversion factor (Ym), and estimated daily emissions are multiplied by number of days to make an estimate of annual emissions per head. Activity data on the population of livestock of each category are multiplied by the EF to estimate total annual emissions from enteric fermentation for that category of livestock.

Implementation of the approach:
Activity data: Livestock population data is provided each year by the Ministry of Agriculture. Emissions are separately estimated for mature dairy cattle and four other types of cattle (Table 2). For the period 1988-2000, livestock population data came from the Yearbooks of the National Statistics Institute. Since 2000, there has been an agreement between the Executive Environment Agency – the centralized unit responsible for inventory compilation – with the Agrostatistics Department of the Ministry of Agriculture and Food (MAF) to provide activity data for the inventory. MAF collects the agricultural statistics through surveys conducted in accordance with European regulations.[7]

Table 2: Livestock categorization in Bulgaria's Tier 2 approach

Dairy cattle	Non-dairy cattle	Sheep
1 category (mature dairy cattle)	4 categories defined by age and sex (mature male, mature female, young male, young female)	4 categories defined by: Age, physiological status (female, male intact, male castrates) and purpose (meat/wool, milk)

Estimation of emission factors: Tables 3 and 4 show the sources of data used when Bulgaria first applied the Tier 2 approach (2010) to dairy and other cattle and in its most recent inventory submission (2017). For dairy cattle, Bulgaria uses country specific data for live weight, calf birth weight, annual milk yield and fat content of milk.

[7] Regulation (EC) No 1165/2008 of the European Parliament.

Since NIR 2017, a country specific value for feed digestibility from a published paper has been used for dairy cattle. All other parameters use IPCC default values. For non-dairy cattle, Bulgaria uses country specific data for live weight and mature weight, and IPCC default values for all other parameters. For sheep, national data on live weight and weight at weaning, milk yield and fat content of milk are used. All other parameters use IPCC default values.

With the exception of digestibility for dairy cattle, country specific values are updated annually. Estimated GE and EFs thus vary year to year. For mature dairy and non-dairy cattle, live weight estimates remain constant over the time series. For young / growing cattle and sheep, live weight estimates vary year to year. The live weight estimates reported by the Ministry of Agriculture are not published data but are reportedly based on measurements. No detail is given in NIRs on how the measurements are conducted. The main drivers of change in emission factors have been an increase in milk yields, change in live weight of young cattle and a decline in the dairy cattle herd, causing a change in the population structure of animals in the 'non-dairy cow' category.

Table 3: Data sources used for Tier 2 estimate of enteric fermentation emissions from mature dairy cattle

Model parameter	**Data source in 2010**	**Data source in 2017**
Average live weight	Ministry of Agriculture	Livestock Breeding Agency
Calf birth weight (kg)	Eq. 7 IPCC 1996 Ref Manual	Ministry of Agriculture
Coefficient for maintenance (Cfi)	IPCC default	IPCC default
% of time spent on pasture		
Coeff. for feeding situation (Ca)	IPCC default	IPCC default
Annual milk yield (kg)	Ministry of Agriculture	Ministry of Agriculture
Average fat content (% fat)	Ministry of Agriculture	Ministry of Agriculture
% pregnant in the year		
Coefficient for pregnancy (Cpreg)	IPCC default	IPCC default
Digestibility	Table 10.2 IPCC 2006 Ref Manual	Scientific publication
Gross energy (GE)	Calculated	calculated
Methane conversion factor (Ym)	Table 4.8 GPG 2000	IPCC 2006 GL
Emission factor	Calculated	calculated

Table 4: Data sources used for Tier 2 estimate of enteric fermentation emissions from non-dairy cattle

Model parameter	**Data source in 2010**	**Data source in 2017**
Average weight	Ministry of Agriculture	Livestock Breeding Agency
Calf birth weight (kg)	Eq. 7 IPCC 1996 Ref Manual	Ministry of Agriculture
Daily weight gain (kg/day)	IPCC default	'default'
Coefficient for maintenance (Cfi)	IPCC default	IPCC default
% of time spent on pasture		
Coeff. for feeding situation (Ca)	IPCC default	IPCC default
Annual milk yield (kg)	Ministry of Agriculture	
Average fat content (% fat)	Ministry of Agriculture	
% pregnant in the year		
Coefficient for pregnancy (Cpreg)	IPCC default	IPCC default
Digestibility	Table 10.2 IPCC 2006 Ref Manual	IPCC default
Gross energy (GE)	calculated	calculated
Methane conversion factor (Ym)	Table 4.8 GPG 2000	
Emission factor	calculated	calculated

The country specific data on milk production and live weight come from surveys conducted by the Agrostatistics Department of MAF. Data on the fat content of milk is obtained from EUROSTAT. Data on live weight is provided by the Agrostatistics Department of MAF. For mature cattle, the data are informed by measurements, but are not formally published data and NIR 2017 notes that the data can be considered 'expert judgement'. These weights are constant over time. For calves and heifers, the data are based on measurements, which change from year to year.

Inventory improvements: Bulgaria's initial application of the Tier 2 model used a mix of country-specific and default data. Over time, the default values used have changed, and the number of parameters using country specific data has increased (Table 5).

Table 5: Cattle enteric fermentation emission inventory improvements in Bulgaria (2011-2017)

	Improvement	Year*
Activity data	-	
Livestock characterization	-	
Emission factors	Used revised country specific values for milk fat content	2017
	Revision of live weight estimation method for young cattle	2014
	Adoption of IPCC 2006 GL Ym default value	2015
	Used country specific value for feed digestibility for dairy cattle	2017
Uncertainty estimation	UNC_{AD} recalculated by Ministry of Agriculture	2017

*Year refers to the year of NIR submission

Revision of live weight data: Until NIR 2014, the inventory used the slaughter body weight of young cattle, but this led to overestimation of the IEF for young cattle. Following an EU Effort Sharing Decision (ESD) review, Bulgaria changed to using average live weight rather than slaughter weight, and recalculated previous inventory estimates.

Revision of country specific value for milk fat content *(2017):* Before 2017, data for milk fat content was provided by the Agrostatistics Department at MAF. In 2017, an official time series from 2006 onwards became available from EUROSTAT, and the emissions time series for dairy cattle was recalculated in 2017 using the new dataset.

Adoption of IPCC 2006 GL Ym value: Prior to NIR 2015, the IPCC GPG 2000 Ym values were used. In 2015, the IPCC 2006 GL values were adopted.

Used country specific value for digestibility for dairy cattle *(2017):* In NIR 2017, a new country-specific value for %DE was used for dairy cattle. This value derived from a scientific publication that used acid insoluble ash as a marker in fresh herbage and faeces to determine digestibility.[8]

Revised UNC_{AD} estimate (2017): For the uncertainty of emission factors, Bulgaria's inventory uses a default uncertainty estimates from IPCC 2006 GL. For activity data, until 2017, the country-specific estimate of activity data uncertainty was 2%, but in 2017 a new estimate of 0.64% was provided by MAF based on examination of whether the livestock population survey precision requirements in EU regulations had been met.

Manure management (Methane)

Approach used: IPCC approach (T2 for cattle and swine), T1 for other livestock.

Implementation of the approach:

- Activity data are taken from national statistics.
- VS excretion rates for the different types of cattle are based on the digestibility and other input values used to estimate GE for enteric fermentation (see above). IPCC default values are used for other parameters required for estimation of VS. For pigs, country-specific VS estimates are based on a

[8] http://www.agrojournal.org/15/02-10-09.pdf

scientific publication, which in turn relied on a combination of published and unpublished literature (Penkov et al. 2014).

- Values for Bo and MCF use IPCC default values.
- The fraction of manure handled in different management systems is based on a survey conducted every 5 years by the Agrostatistics Department at MAF. This survey documents the number of animals per species and category; the quantity fresh manure and nitrogen per animal category; and the nitrogen emitted into different parts of the ecosystem. The data collection methodology is based on the methodologies used by EUROSTAT. The distribution of manure management systems in the intervening years is estimated by extrapolation. This requires recalculation of emission estimates for the years prior to a year with new survey data.

Inventory improvements:

	Improvement	Year*
Activity data	Recategorization of pig manure AWMS	2017
Manure management systems	Revision of MCF for anaerobic lagoons	2015
Emission factors	Re-estimation of young cattle weights based on ESD review	2014
Uncertainty estimation	UNC_{AD} recalculated by Ministry of Agriculture	2017

*Year refers to the year of NIR submission

Bulgaria has made a number of recalculations of manure management emissions in recent years. Among the few that are transparently documented are:

Revision of MCF value for anaerobic lagoons (2015): Prior to 2015, an MCF of 90% was used for anaerobic lagoons. In NIR 2015 this was revised to 70% on the basis of recommendations from expert review.

Recategorization of pig manure AWMS from anaerobic lagoons to liquid storage systems (2017): Prior to 2017, about 90% of pig manure was assigned to anaerobic lagoons. Review of the 2006 IPCC GL definition of anaerobic lagoons at the request of the expert review found that environmental and management factors in Bulgaria are not consistent with this definition. These AWMS were recategorized as liquid storage systems, which have a lower MCF (20%).

Uncertainty management

Prior to NIR 2017, UNC_{AD} was estimated at 2% for all livestock types. In NIR, a new estimate of UNC_{AD} was used. The new UNC_{AD} estimate is based on the official statistical data in the country. It is country specific and based on the Regulation (EC) No 1165/2008 of the European Parliament and of the Council concerning livestock and meat statistics and repealing Council Directives 93/23/EEC, 93/24/EEC and 93/25/EEC. The estimate was made using statistical samples representative of level 6 statistical areas (NUTS2). As a result, UNC_{AD} has been revised in NIR 2017 to 0.64% for cattle, 0.51% for swine and 1.63% for sheep. Total uncertainty for livestock sources has decreased. UNC_{EF} estimates use IPCC defaults.

Further resources:

Bulgaria national inventory reports 2010, 2015, 2017

Penkov, D., Gerzilov, V. and Despotov, H.H.P., 2014. Methods for Determining the Release of Greenhouse Gas Emissions from Pig and Poultry Production in the Republic of Bulgaria. Global Journal of Science Frontier Research: D Agriculture and Veterinary Volume 14 Issue 5. Available at https://globaljournals.org/GJSFR_Volume14/5-Methods-for-Determining-the-Release.pdf

Country inventory case study: Colombia

1. Overview of Colombia's current Tier 2 approach[9]

Agriculture, forestry and other land use (AFOLU) accounts for about 46% of Colombia's net GHG emissions in 2012 (IDEAM et al. 2017). Gross emissions from the AFOLU sector have been falling in recent years, while total removals have increased. Natural forests cover more than half of the country's land area, and cultivated pastures and natural grasslands about one quarter of the total land area. Pasture and grassland are mainly used for extensive cattle grazing. Historically, expansion of pasture has been the main driver of deforestation. Colombia's NDC commits to reduce total national GHG emissions by 20% compared to a business-as-usual scenario, or 30% with international support. Sustainable cattle farming, including silvopastoral systems, are key measures being developed in Colombia to deliver on this target. A Sustainable Bovine Livestock NAMA has been proposed to increase efficiency in cattle production systems and conserve or restore natural ecosystems.

Enteric fermentation in particular is a major source in the AFOLU inventory, accounting for 13% of gross emissions in 2012, 92% of which derives from cattle (IDEAM et al. 2017). Grazing animals also contribute almost 73% of direct N_2O emissions from management of soils. Colombia estimates enteric fermentation from cattle using a Tier 2 approach, and a Tier 1 approach for other livestock emission sources. A Tier 2 approach for cattle enteric fermentation emissions was first adopted in Colombia's Second National Communication submitted in 2010 (IDEAM 2010). The approach has been revised over time. Colombia's Tier 2 approach began by using the IPCC model. In the latest inventory (IDEAM et al. 2017), activity data derived from expert judgement from various industry sources, and emission factors were estimated using the RUMINANT model (Herrero et al. 2013).

2. How Colombia's approach to estimating enteric fermentation emissions has evolved over time

Initial Tier 2 approach: In its 2010 national communication (IDEAM 2010), Colombia reports the results of applying a Tier 2 approach to 4 types of cattle (i.e. dairy and non-dairy cows, and non-dairy mature males and steers) in 24 of the country's sub-national departments (Table 1). Livestock population data was provided by the Ministry of Agriculture and Rural Development (MARD) and industry associations, and was then processed to estimate populations by climate zone for estimation of manure management emissions. The characterization of cattle was based on official national statistics, local research, and interviews with industry experts, including researchers, funding bodies and associations of producers at the regional level (Nieves and Olarte 2009).

Table 1: Evolution of livestock characterization

	Sub-categories	**Regions**
NC 2 (2010)	Dairy: mature female Non-dairy: mature female, mature male	24 departments
BUR 1 (2015)	Dairy: High production cows, low production cows Non-dairy: Cows for meat production Bulls used for reproductive purposes Pre-growing calves Replacement calves Fattening cattle	1 national value
NC 3 (2017)	Dairy: High production cows, low production cows Non-dairy: Cows for meat production Bulls used for reproductive purposes Pre-growing calves Replacement calves Fattening cattle	10 regions

[9] This country case study was produced with valuable inputs from Felipe Torres (Universidad Nacional de Colombia) and Jacobo Arango (CIAT).

BUR1 Tier 2 inventory: In the inventory reported in Colombia's First Biennial Update Report (IDEAM et al. 2015), seven sub-categories of cattle are reported, with one emission factor applied in the country for each cattle category. Activity data for estimation of gross energy intake derived from various sources for different sub-categories, depending on data availability (Table 2).

Table 2: Activity data sources used in BUR 1 Tier 2 approach (IDEAM et al. 2015)

Parameter	Data sources
Live weight	Databases and published reports of FEDEGAN (Colombian Federation of Cattle Ranchers); Expert judgement by staff and consultants from FEDEGAN, UNDP, IDEAM and FAO Analysis of National Administrative Department of Statistics (DANE) livestock slaughter survey (ESAG) data
Weight gain	Publications of FEDEGAN Expert judgement by staff and consultants from FEDEGAN, UNDP, IDEAM and FAO
Milk yield	Publications of FEDEGAN Expert judgement based on data from the FEDEGAN modal farm database
Feed digestibility	Expert judgement by staff and consultants of FEDEGAN, UNDP, IDEAM and FAO

Source: IDEAM et al. (2015)

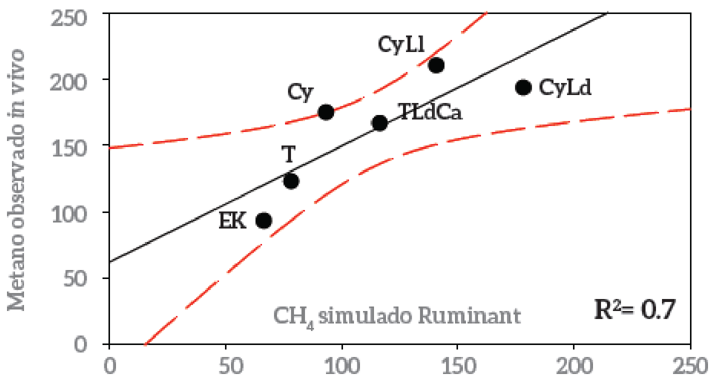
Third National Communication: The Third National Communication (IDEAM et al. 2017) introduced a further refinement of the Tier 2 approach. Building on an ongoing programme of research conducted by the International Center for Tropical Agriculture (CIAT), the most recent approach uses the RUMINANT model to estimate emission factors for different types of cattle in 10 regions in the country.

The RUMINANT model: The RUMINANT model was developed to predict feed intake, livestock productivity and methane emissions in tropical conditions on the basis of animal and feed characteristics (Herrero *et al.*, 2013). The model estimates intake based on animal characteristics and nutrient supply. Based on the chemical composition of feed, the model simulates the degradation and passage of feed. From this, metabolisable energy and protein supply to the animal is estimated, as well as other outputs, including methane production. RUMINANT simulates on a daily time step.

Validation of the RUMINANT model: With the finantial support from USAID in the frame of the LivestockPlus project of CCAFS[10], CIAT is undertaking ongoing research to validate the capacity of the RUMINANT model to simulate enteric CH_4 emissions under Colombian conditions. Prior to preparation of the Third National Communication, a short study was conducted using cattle fed on seven forage-based diets combinations, including 3 single forage diets and 4 mixed forage diets. Methane emission was estimated through both in vitro and in vivo (polytunnel) methods (Lockyer and Jarvis 1995, Theodorou et al. 1994). The data on livestock and feed characteristics were used to run the RUMINANT model, and researchers then compared the CH_4 emissions estimated with observed and simulated data (Ruden-Restrepo et al. 2017; Serena et al. 2017). The results showed that the RUMINANT model provided an accurate estimate of methane emissions, with a correlation coefficient (R^2) between observed in vivo measurements and simulated data of 0.7 (Figure A). Correlations were particularly high for some of the mixed diets tested. Compared with the in vitro measurement data, the model had an even higher correlation (R^2 = 0.92) (Figure B).

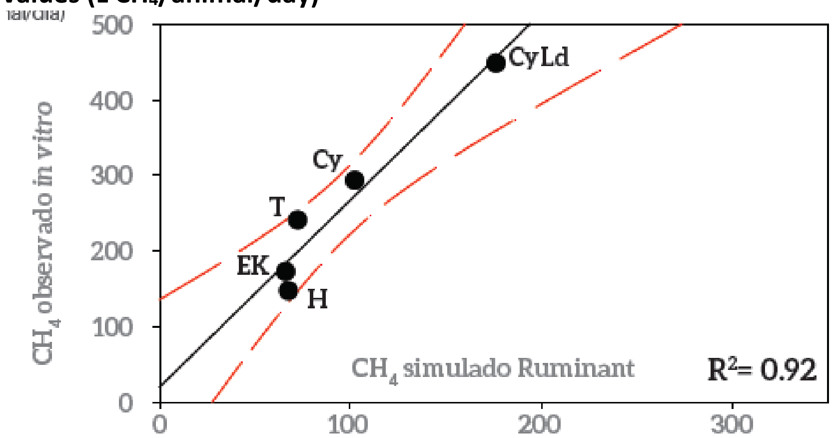
[10] https://ccafs.cgiar.org/supporting-low-emissions-development-latin-american-cattle-sector-livestockplus#.Ww6EAjQvzIU

Figure A: Relationship between observed in vivo methane measurement values and simulated values (L CH_4/animal/day)



Source: Ruden-Restrepo et al. 2017

Figure B: Relationship between observed in vitro methane measurement values and simulated values (L CH_4/animal/day)



Application of the RUMINANT model in the national inventory: CIAT provided training to the national inventory compilation agency on the use of the RUMINANT model software. The model was parameterised using data on regional characteristics of each type of animal were collected by the Agricultural Synergies project, a Norweigian funded research project implemented by FEDEGAN, CIAT and University of Princeton. The data were collected through 5 workshops conducted with academics, livestock producers and agronomists in different regions of the country during which information on typical production systems were recorded. Data for seven different animal types in 10 regions and typical feed characteristics was input into the RUMINANT model. The model estimated daily methane emissions per animal. The inventory then applies this emission factor to the population data in each animal category and number of days alive.

The validated models can also be applied to ex ante assessment of livestock mitigation options in the Sustainable Bovine Livestock NAMA.

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Lockyer, D.R. and Jarvis, S.C., 1995. The measurement of methane losses from grazing animals. *Environmental Pollution*, *90*(3), pp.383-390.

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Ruden-Restrepo, A. et al 2017. Validación del modelo Ruminant a través de mediciones de campo y laboratorio para obtener estimaciones precisas de emisiones de metano entérico bajo condiciones tropicales como soporte a las NDC Colombianas. Poster presented at 3a. Conferencia de Gases de Efecto Invernadero en Sistemas Agropecuarios de Latinoamérica (GALA 2017), Colonia, Uruguay.

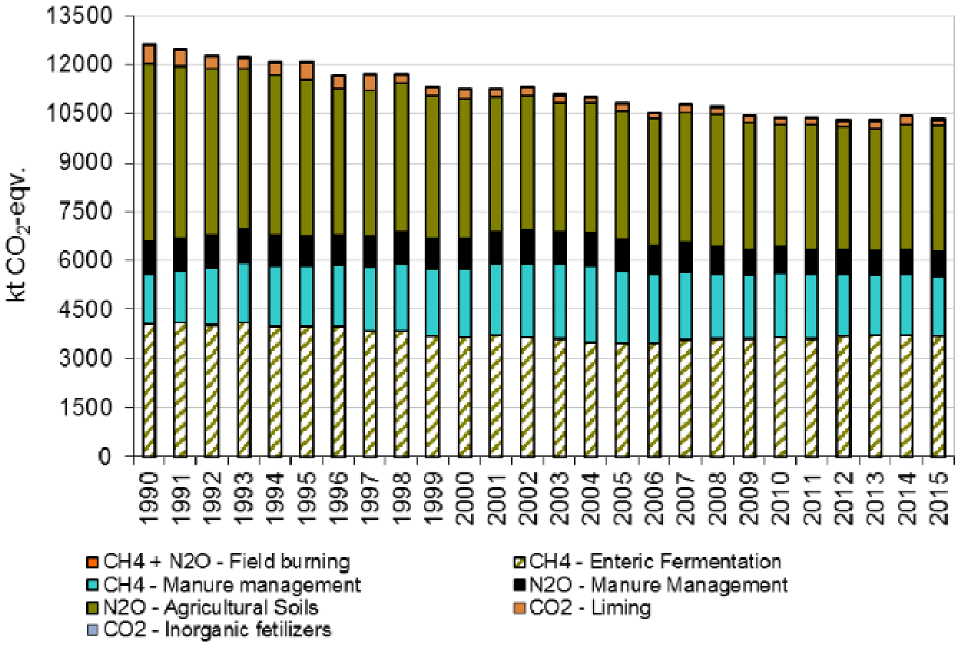
Serena, L. et al. 2017 Validación del modelo RUMINANT para obtener estimaciones precisas de las emisiones de metano entérico en condiciones tropicales para apoyar las Contribución Prevista Determinada a Nivel Nacional (NDC) Colombianas. Available at: https://www.slideshare.net/cgiarclimate/validacin-del-modelo-ruminant-para-obtener-estimaciones-precisas-de-las-emisiones-de-metano-entrico-en-condiciones-tropicales-para-apoyar-las-contribucin-prevista-determinada-a-nivel-nacional-ndc-colombianas/1

Theodorou, M.K., Williams, B.A., Dhanoa, M.S., McAllan, A.B., France, J., 1994. A simple gas production method using a pressure transducer to determine the fermentation kinetics of ruminant feeds. Anim. Feed Sci. Technol. 48, 185±197.

Country inventory case study: Denmark

The agriculture sector in Denmark contributes 21% of the country's overall GHG emissions, excluding LULUCF. Denmark's agriculture emissions are dominated by the livestock sector, primarily due to the production of dairy and non-dairy cattle and swine. Methane (CH_4) is the largest contributor to the overall agricultural emissions, accounting for 54% of the sector's CO_2-equivalents in 2015 (Figure A).

Figure A Greenhouse gas emissions by the agriculture sector from 1990 - 2015[11]



Source: Denmark NIR 2017

Overview of Denmark's current Tier 2 approach

Denmark adopted the IPCC Tier 2 approach for cattle enteric fermentation in the 1990s. In 2003, a thorough revision of the inventory methodology was undertaken, leading to extension of the Tier 2 approach to other animal types and adoption of a country-specific refinement to the IPCC Tier 2 approach.

Table 1: Tiered approaches used for livestock in Denmark's national GHG inventory

Livestock types	Tier used for enteric fermentation (CH_4)	Year adopted*	Tier used for manure management (CH_4)	Year adopted*
Dairy cattle	T2	Before 2003	T2	Before 2003
Non-dairy cattle	T2	Before 2003	T2	Before 2003
Sheep	T2	2004	T2	2004
Pigs	T2	2004	T2	2004
Other (horses, goats, deer)	T2	various	T2	Various

*Year refers to the year of NIR submission

Table 2: Livestock categorization method

[11] From 1990 to 2015, emissions decreased from 12.6 million tonnes CO_2 equivalents to 10.3 million tonnes CO_2 equivalents (~18% reduction). The total N_2O emission from 1990-2015 decreased by 28% and can largely be attributed to the decrease in N_2O emissions from agricultural soils. A 9% reduction in methane emissions from enteric fermentation over the last years can mainly be explained by a reduction in cattle number.

Dairy cattle	Non-dairy cattle	Swine
35 categories based on animal type (defined by age, physiological status, breed) and housing system	129 categories based on animal type (defined by age, physiological status, breed) and housing system	3 categories: sows, weaners, fattening pigs

Calculation of enteric fermentation emissions from cattle

Emissions from enteric fermentation are calculated using a methodology based on 2006 IPCC Guidelines. A Tier 2 approach is used for all ruminants and swine. Calculations for cattle are based on the sum of emissions in the winter and summer feeding seasons (Figure B). During the summer the ration mainly consists of grass, whereas during the winter roughage and concentrate feeds are fed. The equations for dairy cattle used to specifically include sugar beets in the winter ration, which result in higher methane emissions. However, in recent years sugar beet production in Denmark has declined significantly and they are no longer a major part of the feed ration.

Figure B Denmark's equation for emission factor calculation for dairy cattle

$$EF = EF_{winter} + EF_{summer}$$

Dairy cattle:

$$EF_{winter,dairy\ cattle} = F \cdot \left(\left(\frac{GE_{F\ winter}}{55.65}\right) \cdot Y_{m\ excl\ sugar\ beet} \cdot \left(1 - \frac{grazing\ days}{365} - \frac{days\ with\ sugar\ beet}{365}\right) + \left(\frac{GE_{F\ winter}}{55.65}\right) \cdot Y_{m\ incl\ sugar\ beet} \cdot \frac{days\ with\ sugar\ beet}{365} \right)$$

$$EF_{summer,dairy\ cattle} = F \cdot \left(\frac{GE_{F\ summer}}{55.65}\right) \cdot Y_{m\ grazing} \cdot \frac{grazing\ days}{365}$$

Where:

EF_{winter} = Emission factor for winter feed, kg CH_4 per head per year

EF_{summer} = Emission factor for summer feed, kg CH_4 per head per year

F = feed, kg DM

$GE_{F,winter}$ = gross energy per kg DM, MJ per kg DM in winter

$GE_{F,\ summer}$ = gross energy per kg DM, MJ per kg DM in summer

Y_m = methane conversion factor, per cent of gross energy in feed converted to methane

55.56 = energy content of CH_4, MJ per CH_4

Source: Denmark's NIR 2017

Calculation of gross energy per kg DM relies on the Danish Normative System. The Danish Normative System is used for fertilizer planning and control by Danish famers and authorities (Poulsen et al. 2001, Poulsen 2016). The Danish normative standards are based on practical farming and thus reflect actual Danish agricultural production characteristics. The normative standards are developed annually by the Danish Centre for Food and Agriculture (DCA) on the basis of data received from SEGES, which is the central office for all Danish agricultural advisory services. SEGES collects efficacy reports from Danish farmers, to optimize productivity in Danish agriculture, as well as conducting other research.

In the dairy sector, 10% of the Danish farmers are part of an intensive monitoring system. Four to five times a year, detailed data including livestock numbers, animal weight and feeding plans (e.g. rations, nutrient content) is collected. This includes any feed bought from outside the farm. Furthermore, 50% of the Danish farmers participate in an annual monitoring system, which includes 'spot' samples on feeding plans. Data collected from the 50% of farmers are compared with the 10% farmers who are monitored in greater detail and more intensively. This comparison serves data verification purposes and gives an indication whether the 10% can serve as 'model farmers' for the normative system. Based on the very detailed production data, normative standards are then established. In total the normative standards cover feed plans from 15-18% of the Danish dairy production. Previously, the normative standards were updated and published every third or fourth year. Since 2001 these standards have been updated annually and are available to download from the homepage of DCA (http://anis.au.dk/forskning/sektioner/husdyrernaering-og-fysiologi/normtal/).

To calculate the total gross energy (GE) intake, the GE per kg DM (GFF) or GE per feed unit (GEFU) is estimated. A feed unit in Denmark is defined as the feed value in 1.00 kg barley with a dry matter content of 85%. For other cereals, e.g. wheat and rye, one feed unit is 0.97 kg and 1.05 kg, respectively.

For dairy cattle, gross energy intake is estimated by DCA, based on detailed data from feeding plans as collected annually by SEGES. From 2014 feed intake for dairy cattle given in the normative figures are given in kg DM per year and the energy in the feed is given in MJ per kg DM. The energy intake is a standard winter feed regardless of whether the animal grazes or not. For all livestock categories other than dairy cattle, the estimation of gross energy (GEFU) is based on the composition of feed intake and the energy content in proteins, fats and carbohydrates based on feeding controls or actual feeding plans at farm level, collected by SEGES or DCA. In contrast to dairy feed data, this feeding data is collected every 3 to 4 years**.** The data are given in Danish feed units or kg feedstuff and these values are converted to mega joule (MJ):

$$GE_{FU} = \frac{MJ/day}{FU/day}$$

$$FU/day = \frac{kg\ dm}{day} \cdot \frac{FU}{kg\ dm}$$

$$MJ/day = \frac{kg\ dm}{day} \cdot \frac{MJ}{kg\ dm}$$

$$MJ/kg\ dm = \%_{Crude\ protein} \cdot E_{Crude\ protein} + \%_{Raw\ fat} \cdot E_{Raw\ fat} + \%_{Carbonhydrates} \cdot E_{Carbonhydrates}$$

$$\%_{Carbonhydrates} = 100 - (\%_{Crude\ protein} + \%_{Raw\ fat} + \%_{Raw\ ashes})$$

Source: Denmark NIR 2017

Feeding data collected by SEGES have shown a shift in feeding practices from sugar beets to maize (whole cereal). Due to the higher content of easily convertible sugar, sugar beets resulted in higher methane emissions than maize or grass. This change in feeding practices is reflected in the average methane conversion factor (Table 3).

Table 3 Development of Denmark's methane conversion rate (Ym) for dairy cattle and heifers > 0.5 years between 1990 and 2015 (%)

	1990	1991	1995	2000	2002 - 2015
Ym incl. sugar beet	6.70	6.70	6.45	6.13	6.00
Ym excl. sugar beet	6.00	6.00	6.00	6.00	6.00
Ym grazing	6.00	6.00	6.00	6.00	6.00
Ym average	6.38	6.38	6.24	6.07	6.00

Source: Denmark's NIR 2017

The estimation of the national methane conversion factors is based on the model 'Karoline' developed by DCA and is based on the average feeding plans obtained from SEGES (Olesen et al. 2005). Initially, DCA estimated methane emissions for a winter feeding plan for two years, 1991 (Ym=6.7) and 2002 (Ym=6.0) and estimated Ym for the years between 1991 and 2002 using interpolation. New measurements by Hellwing et al. (2014) resulted in new methane conversion factors of between 5.98 and 6.13.

Figure C: Integrated database model for agricultural emissions, Denmark

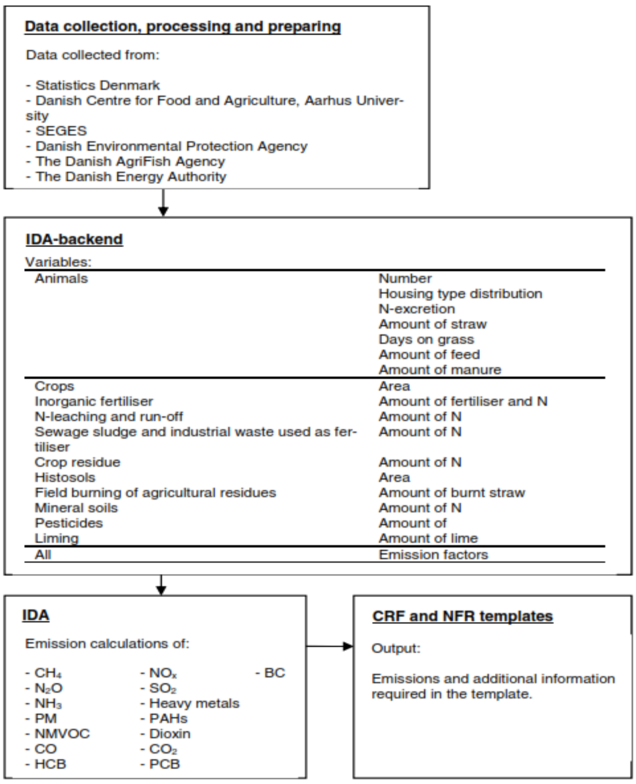


Figure 5.2 IDA - Integrated Database model for Agricultural emissions.

Source: Denmark NIR 2017

Manure management emissions

The emissions from the agricultural sector are calculated in a comprehensive agricultural model complex called IDA (Integrated Database model for Agricultural emissions, Figure C). The model is designed in a relational database system (MS Access). Input data are stored in tables in one database called IDA Backend and the calculations are carried out as queries in another linked database called IDA. This model complex is implemented in great detail and is used to cover emissions of air pollutants and greenhouse gases. There is therefore a direct coherence between input data used to estimate enteric fermentation and manure management methane emissions, as well as between this and the data used to estimate ammonia (NH_3) and N_2O emissions.

Most emissions relate to livestock production, which is based on information on the number of animals, the distribution of animals according to housing type and information on feed consumption and excretion. IDA operates with 39 different livestock categories, according to livestock type, weight class and age. These categories are subdivided into housing type and manure type, which results in 269 different combinations of livestock sub-categories and housing types. For each of these combinations, information on feed intake, digestibility, excretion, grazing days and other parameters is included. The emission is calculated from each of these subcategories and then aggregated in accordance with the IPCC livestock source categories given in the Common Reporting Formats.

Roles and responsibilities in inventory compilation

Activity data and emission factors are collected and discussed in cooperation with specialists and researchers in various institutes with agricultural expertise, including SEGES, DCA, Aarhus University and Statistics Denmark. An overview of key institutes and organisations involved in Denmark's agriculture emission inventory, and key data/information collected is provided in Table 4.

The Danish Centre for Environment and Energy (DCE) and Aarhus University have established data agreements (MOUs) with the institutes and organisations to ensure that the required data is available to prepare the emission inventory on time. Data is shared with DCE and Aarhus University, and updated in the Integrated Database Model on an annual basis. Close cooperation between research and advisory services (SEGES) allows research to work with actual and high quality data, while advisory services have actual core data to its disposal enabling high quality advisory services and the provision of benchmarks to their farmers.

Table 4 Institutes involved in Denmark's agriculture emission inventory

Institute	Key data/information collected
Statistics Denmark – Agricultural Statistics	• Livestock production • Milk yields • Slaughtering data • Export of live animals – poultry • Land use • Crop production • Crop yields
Danish Centre for Food and Agriculture (DCA), Aarhus University	• N-Excretion • Feeding plans • Animal growth • Use of straw for bedding • N-content in crops • Modelling of data regarding N-leaching/runoff • NH3 emission factor
SEGES	• Housing type (until 2004) • Grazing situation • Manure application time and methods • Estimation of extent of field burning of agricultural residues • Acidification of slurry

Source: adapted from Denmark's NIR 2017

Factors contributing to development of the approach over time

Data availability has played a key role in the development of Denmark's approach. Due to the European Nitrates Directive coming into force in 1991, a nation-wide monitoring programme was established in Denmark. All aspects of the aquatic environment, including key drivers of nitrogen leaching, such as the agriculture sector, were included in the monitoring programme.

In 1996, SEGES and Aarhus University realized that the nation-wide monitoring programme resulted in a great source of detailed information on agriculture practices, including feeding practices and manure management. Since 1996 this data has thus been integrated in the national GHG inventory, which enabled the shift from a Tier 1 to Tier 2 approach.

The availability of the database of feeding plans has likewise facilitated the development of country-specific methane conversion factors. This database exists due to the strong farmer advisory system in the country. Denmark's first agricultural advisory was as early as 1874. Farmers participating in the annual monitoring are mainly interested in the performance benchmarks the monitoring system produces. At the same time, the resulting data provide actual and up to date input data for use in the national inventory.

Further resources

Denmark national inventory report 2017

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Country inventory case study: Estonia

1. Overview of Estonia's current Tier 2 approach

Although the total population of livestock has been decreasing since 1990, enteric fermentation from cattle is a key source in the national inventory, accounting for about 95% of methane emissions from livestock (NIR 2017). Manure management methane emissions from dairy cattle are a key category by trend. Estonia began using a Tier 2 approach for cattle enteric fermentation emissions in 2007, and subsequently adopted Tier 2 approaches for manure management methane emissions and methane emissions from pigs in 2010 (Table 1).

Table 1: Overview of Tiers used for livestock methane emissions in Estonia's national GHG inventories

Livestock types	Tier used for enteric fermentation (CH_4)	Year adopted*	Tier used for manure management (CH_4)	Year adopted*
Dairy cattle	T2	2007	T2	2010
Non-dairy cattle	T2	2007	T2	2010
Sheep	T1	-	T1	-
Pigs	T2	2010	T2	2010
Other	T1	-	T1	-

*Year refers to the year of NIR submission

2. Enteric fermentation

Description of approach: Estonia implements the IPCC Tier 2 model for cattle. The approach estimates daily gross energy (GE) intake on the basis of animal performance, management practices and environmental factors. GE is converted to methane using a methane conversion factor (Ym), and estimated daily emissions are multiplied by number of days to make an estimate of annual emissions per head. Activity data on the population of livestock of each category are multiplied by the EF to estimate total annual emissions from enteric fermentation for that category of livestock.

Implementation of the approach:
Activity data: Livestock population data is provided each year by Statistics Estonia, which provides population data for each of the 11 counties in the country. Initially, emissions were separately estimated for dairy cattle and 4 other types of cattle in each county (Table 2). Subsequently, a review recommended separate calculations for calves <6 months old, which are now estimated as 50% of the population of calves <1 years old. In 2017, the former method of calculating emissions by county and aggregating results to national level was replaced by a single calculation at national level using the weighted average of activity data from the counties.

Table 2: Livestock categorization in Estonia's Tier 2 approach

	Sub-categories	**Regions**
NIR 2010	Dairy: mature female Non-dairy: mature female, mature male, steers, calves <1 year old	11 counties
NIR 2017	Cattle >2 years old: dairy cattle, non-dairy mature females, non-dairy mature males Cattle 1-2 years old Calves 6-12 months old Calves 0-6 months old	1 calculation at country level using weighted average of activity data from sub-regions

Estimation of emission factors: Table 3 shows the sources of data used when Estonia first applied the Tier 2 approach (2007) to dairy and other cattle and the sources used in its most recent inventory submission (2017). Estonia's initial Tier 2 approach for cattle used a mixture of IPCC default values and national statistical data:

- Apart from the standard coefficients in the IPCC model, default values were used for live weight, feed digestibility and the methane conversion factor.
- Subsequently, national data for cattle live weight was obtained from the Estonian Animal Recording Centre (EARC), which also provided data on milk fat content and % of cows giving birth in each year. The EARC collects animal performance data on dairy cattle by breed. A weighted average of live weights is estimated and used as the estimate of live weight in the national inventory.
- The initial estimate of feed digestibility was from the IPCC guidelines. Subsequently, a scientific publication from the country was used as the data source (Kaasik et al. 2002).

For dairy cattle, data on cattle weight, milk yield and fat content, and the % of cows giving birth are updated annually on the basis of data obtained from statistics agencies and the animal recording centre. Estimated GE and EFs thus vary year to year. For non-dairy cattle, live weight estimates, which are derived from IPCC default values and national research, do not vary from year to year.

Table 3: Data sources used for Tier 2 estimate of enteric fermentation emissions for dairy cattle in Estonia

Model parameter	Data source in 2007	Data source in 2017
Average live weight	IPCC 1996	EARC
Daily weight gain (kg)	Literature from own country	EARC
Coefficient for maintenance (Cfi)	IPCC 1996	IPCC 2006 GL
% of time spent on pasture	-*	-*
Coeff. for feeding situation (Ca)	IPCC 1996	IPCC 2006 GL
Annual milk yield (kg)	Statistics Estonia	Statistics Estonia
Average fat content (% fat)	EARC	EARC
% pregnant in the year	EARC	EARC
Coefficient for pregnancy (Cpreg)	IPCC 1996	IPCC 2006 GL
Digestible energy (%DE)	IPCC 1996	Literature from own country
Gross energy (GE)	Calculated	Calculated
Methane conversion factor (Ym)	IPCC 1996	IPCC 2006 GL
Emission factor	Calculated	calculated

* indicates no data source cited.
Source: NIR 2007, NIR 2017

3. Manure management (Methane)

Approach used: IPCC approach (T2 for cattle and swine), T1 for other livestock.

Implementation of the approach: Livestock population data are taken from national statistics, using the same sources as are used for enteric fermentation. In Estonia's initial Tier 2 approach for methane emissions from cattle manure management, the default values from the IPCC 1996 Guidelines (Reference Manual) were used for all parameters. Estonia continues to use default values for ash content, the maximum amount of methane able to be produced from that manure (Bo) and the methane conversion factor (MCF). Country-specific data are now used for feed digestibility, and the proportion of manure managed in different systems is estimated using expert judgement to replace the IPCC default MMS values.

Table 4: Data sources used for Tier 2 estimate of methane emissions from manure management in Estonia

Model parameter	Data source in 2010	Data source in 2017
GE	Calculated	Calculated
%DE	IPCC 1996 defaults	Literature from own country
Ash content	IPCC 1996 defaults	IPCC 2006 defaults
Bo	IPCC 1996 defaults	IPCC 2006 defaults for E Europe
Proportion of manure managed in different systems (MMS)	IPCC 1996 defaults	Expert opinion from Estonian Environmental Research Centre

MCF	IPCC 1996 defaults	IPCC 2006 defaults

4. Uncertainty management

Estonia does has no country-specific estimates of the uncertainty rates of activity data. Estimates were obtained from an Austrian publication (Rypdal and Winiwarter, 2001), where uncertainties of livestock population data from Austria, Norway, the Netherlands and USA are presented. Estonia assumes activity data uncertainty is the same as the Austrian uncertainty estimate. Uncertainty of emission factors is estimated using the IPCC default values.

Table 5: Estimated uncertainty values in Estonia's livestock inventory

Input	Uncertainty	Reference
Activity data		
Livestock populations	±10%	Rypdal and Winiwarter, 2001
Emission factors		
Enteric fermentation (cattle, pigs)	±20%	IPCC 2006 Vol 4 Ch 10, p.10.33
Enteric fermentation (sheep, goats, horses, fur animals)	±40%	

Source: Estonia NIR 2017

Further resources:

Estonia national inventory reports 2007, 2010, 2017

Kassik, A., R. Leming, and T. Remmel. "Nutrient losses (N, P, K) in dairy-and pig production." *Journal of Agricultural Science*(2002).

Rypdal, K. and Winiwarter, W., 2001. Uncertainties in greenhouse gas emission inventories—evaluation, comparability and implications. *Environmental Science & Policy*, *4*(2-3), pp.107-116.

Country inventory case study: Japan

1. Overview of Japan's current Tier 2 approach

Total emissions from enteric fermentation was identified as a key category in Japan's 1990 inventory, and are still a key category in the latest inventory submission (NIR 2018). Nitrous oxide from manure management, but not methane from manure management, is a key category. Japan reports enteric fermentation emissions from dairy and non-dairy cattle using a Tier 2 approach. A Tier 1 approach is used for enteric fermentation from all other livestock types. Methane emissions from manure management are estimated using a Tier 2 approach with a combination of country-specific and default emission factors, depending on the manure management system. Japan's specific approach adopted for both enteric fermentation and manure management methane emissions has evolved over time.

Table 1: Overview of Tiers used for livestock methane emissions in Japan's national GHG inventories

Livestock types	Tier used for enteric fermentation (CH_4)	Year adopted	Tier used for manure management (CH_4)	Year adopted
Dairy cows	T2	mid-1990s	T1/T2	1990s
Non-dairy cows	T2	mid-1990s	T1/T2	1990s
Pigs	CS T1*	early 1990s	T1/T2	1990s
Buffalo	T1	-	T1	-
Sheep	T1	-	T1	-
Goats	T1	-	T1	-
Horses	T1	-	T1	-

*Tier 1 approach with country-specific emission factor.

2. Enteric fermentation

Approach used: Country-specific model

Why was this approach adopted? Following the IPCC Guidelines, Japan adopted a Tier 2 approach, but decided to follow the common practices in Japanese livestock research of estimating emission factors on the basis of dry matter intake.

Description of approach: Japan's country-specific model is based on a relationship between emissions and dry matter intake (DMI). The approach has evolved over time through changes in livestock categorization and methods used to estimate DMI of different cattle sub-categories.

Research published in the early 1990s (Shibata et al 1993) showed that for ruminants the volume of methane emitted per head per day could be related to dry matter intake using the equation:

$$Y = -17.766 + 42.793X - 0.489X^2$$

where Y is the volume of methane generated (liters/day) and X is dry matter intake (kg/day). Japan's inventory continues to use this equation.

Emission factors for each type of animal are estimated using average dry matter intake as recorded in the *Japan Feed Standards*, which is compiled by the Japan Livestock Industry Association. In the feed standards, DMI is estimated using an equation based on fat corrected milk yield, body weight, and daily weight gain by daily growth, where fat corrected milk is updated on the basis of annual official statistics. In 2006 and 2008, the equations used to estimate DMI of different sub-categories were updated for dairy and non-dairy cattle, respectively (Table 2).

Table 2: Equations used to estimate DMI by cattle in Japan

Dairy cattle	Lactating	After 2006: $DMI=1.3922+0.05839\times W^{0.75}+0.40497\times FCM$ $FCM=(15\times FAT/100+0.4)\times MILK$ Before 2005: $DMI=2.98120+0.00905\times W+0.41055\times FCM$ $FCM=(15\times FAT/100+0.4)\times MILK$
	Non-lactating	After 2006: $DMI=0.017\times W$ Before 2005: $DMI=(0.1163\times W^{0.75}/0.82)/4.41/0.52*1.1$
	Heifers	$DMI=0.49137+0.01768\times W+0.91754\times DG$
	Breeding cows	$DMI=[0.1067\times W^{0.75}+(0.0639\times W^{0.75}\times DG)/(0.78\times q+0.006)]/(q\times 4.4)$ $q=0.4213+0.1491\times DG$
Non-dairy cattle	Japanese cattle (M)	After 2008: $DMI=-3.481+2.668\times DG+4.548\times 10^{-2}\times W-7.207\times 10^{-5}\times W^{2}+3.867\times 10^{-8}\times W^{3}$ Before 2007: $DMI=[0.1124\times W^{0.75}+(0.0546\times W^{0.75}\times DG)/(0.78\times q+0.006)]/\{q\times(1.653-0.00123\times W)\}$ $q=0.5304+0.0748\times DG$
	Japanese cattle (F)	$DMI=[0.1108\times W^{0.75}+(0.0609\times W\text{^}0.75\times DG)/(0.78\times q+0.006)]/(q\times$ $q=0.5018+0.0956\times DG$
	Dairy breeds (excl. 5-6 m old)	$DMI=[0.1291\times W^{0.75}+(0.0510\times W^{0.75}\times DG)/(0.78\times q+0.006)]/(q\times 4.4)$ $q=(0.933+0.00033\times W)\times(0.498+0.0642\times DG)$
	Dairy breeds (5-6 m old)	$DMI=[0.1291\times W^{0.75}+\{(1.00+0.030\times W\text{^}0.75)\times DG\}/(0.78\times q+0.006$ $q=(0.859-0.00092\times W)\times(0.790+0.0411\times DG)$

W: weight, FCM: fat corrected milk, FAT: fat content of milk, MILK: Milk yield, DG: daily growth, q: energy metaboloc rate.

Source: NIR 2012

Livestock population numbers for each type of cattle come from official statistics documented in a survey at 1 February each year by the Ministry of Agriculture, Forestry and Fisheries. Initially, inventory sub-categories included 3 types of dairy cattle (lactating, dry and heifers) and 4 types of non-dairy cattle (breeding cows, fattening cattle <1 year and >1 year old, and dairy breeding animals). The inventory excluded cattle under 6 months old, which were assumed to account for 50% of the population of cattle categories under 1 year old. Subsequently, 5 and 6 month old cattle were identified as a separate sub-category, and fattening cattle were divided into male and female sub-groups of different ages and sub-groups defined by breed (NIR 2006). An inventory review in 2016 pointed out that cattle over 3 months old emit methane, and in NIR 2017, calves between 3 and 6 months were added as another sub-category.

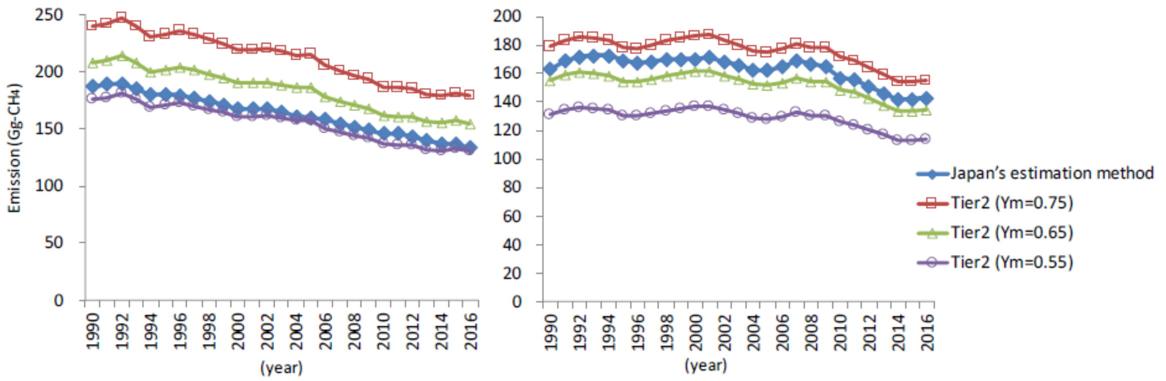
Table 3: Emission factors for cattle in Japan’s national inventory

Animal Type			Unit	1990	1995	2000	2005	2009	2010	2011
Dairy Cattle		Lactating	kgCH4/head/year	125.0	128.3	130.0	131.9	132.1	131.8	132.2
		Non-lactating	kgCH4/head/year	72.0	72.7	74.0	74.1	88.7	88.7	88.9
		Heifer: Under Two Years, over six months	kgCH4/head/year	63.4	64.7	66.9	67.8	68.0	68.0	68.1
		Heifer: Five and six months	kgCH4/head/year	32.7	32.9	34.4	38.1	38.8	38.8	38.9
Non-Dairy Cattle	Breeding Cows	One Year and Over	kgCH4/head/year	59.0	59.2	63.1	59.3	57.0	57.0	57.1
		Under One Year, over six months	kgCH4/head/year	49.8	50.0	60.1	56.3	53.8	53.8	54.0
		Five and six months	kgCH4/head/year	34.9	35.0	40.4	37.8	36.2	36.2	36.3
	fattening cattle	Japanese cattle (M): One Year and Over	kgCH4/head/year	73.2	73.4	73.2	72.8	68.5	68.5	68.7
		Japanese cattle (M): Under One Year, over six months	kgCH4/head/year	61.1	61.3	61.1	61.2	64.5	64.5	64.7
		Japanese cattle (M): Five and six months	kgCH4/head/year	39.6	39.7	39.6	39.9	39.8	39.8	39.9
		Japanese cattle (F): One Year and Over	kgCH4/head/year	51.8	51.9	58.1	54.2	51.9	51.9	52.0
		Japanese cattle (F): Under One Year, over six months	kgCH4/head/year	44.3	44.5	55.3	51.2	48.7	48.7	48.8
		Japanese cattle (F): Five and six months	kgCH4/head/year	31.0	31.0	37.4	34.6	32.9	32.9	33.0
		Dairy breed: Over six months	kgCH4/head/year	75.6	75.8	75.6	75.6	75.6	75.6	75.8
		Dairy breed: Five and six months	kgCH4/head/year	48.0	48.1	48.0	48.0	48.0	48.0	48.1

Source: NIR 2012

Japan has undertaken studies to compare the results of estimation using its country-specific approach and the IPCC model. Using available national data and IPCC default values for Ym, C_{fi} and $C_{pregnancy}$, enteric fermentation emissions were estimated using the IPCC model. The results show that there are no significant differences between the estimates made using the two approaches (Figure 1).

Figure 1: Comparison of results of Japan’s country-specific estimation method and IPCC Tier 2 method for dairy cattle (left) and non-dairy cattle (right)



Source: NIR 2018

3. Manure management (Methane)

In its early inventories, manure management methane emissions from cattle, pigs and poultry were estimated using measurements conducted on different manure management systems in Japan (JLTA 1999, JLTA 2002, Fukumoto et al. 2001). Subsequently, a mixed approach was adopted whereby national emission factors were used if there was reliable data, and IPCC default values were used if appropriate EFs from other countries were not available (see Inventory Practice: Choice of emission factors in Japan). EFs established using Japanese research are based on direct measurements, and the use of country-specific values has increased over time. For example, NIR 2018 uses country-specific values for the methane EFs from pit storage and biogas digesters. This was based on actual measurements in 9 regions of the country using the floating chamber method (MAFF 2012). The integrated EF for the country is the average of regional EFs weighted by the dairy cattle population in the country (NIR 2018).

Table 4: Manure methane emission factors for cattle, pigs and poultry in Japan's inventory

treating method		Daily Cattle		Non-daily cattle		Swine		Hen, Broiler	
12. Pit storage		3.90 %	D	3.00 %	D	8.7 %	D	—	—
13. Sunlight drying		0.20 %	J	0.20 %	J	0.20 %	J	0.20 %	J
14. Other	13a. Thermal drying	0 %	Z	0 %	Z	0 %	Z	0 %	Z
	13b. Composting (feces)	0.044 %	D	0.034 %	D	0.097 %	D	0.14 %	J
	13c. Deposition	3.80 %	J	0.13 %	J	0.16 %	J	0.14 %	J
	13d. Incineration	0.4 %	O	0.4 %	O	0.4 %	O	0.4 %	O
	13e. Composting (feces and urine mixed)	0.044 %	D	0.034 %	D	0.097 %	D	—	—
	13f. Wastewater management	0.0087%	D	0.0067%	D	0.019%	D	—	—

Note: D = IPCC default; J = Japan; O = other countries; Z = not applicable.
Source: NIR 2006

Data on the proportion of animal waste managed in different systems derived from different sources. In 1997, a survey was conducted prior to enforcement of the "Act on the Appropriate Treatment and Promotion of Utilization of Livestock Manure". This act prohibits inappropriate manure management practices and induced changes in the proportion of manure managed in different systems. A second survey was conducted in 2009, and data for years between 1997 and 2009 were interpolated. From 2009 onwards, results of an annual national survey conducted by MAFF have been used.

4. Uncertainty management

For cattle, the uncertainties of emission factors were calculated by finding the 95% confidence interval in accordance with the equation used to estimate the emission factors (Dairy cattle: -26% to +32%, non-dairy cattle: -40% to +49%). Populations of cattle (activity data) are based on data from the official *Livestock Statistics*, but standard error for cattle is not described in the official statistics. Therefore, the uncertainties for activity data were substituted by 1% error estimated for swine in the *Livestock Statistics.* As a result, the uncertainties of the emissions were determined to be -26% to +32% for dairy cattle and -40% to +49% for non-dairy cattle.

The uncertainties for emission factors of livestock other than swine were apply the 50% default data given in the *2006 IPCC Guidelines*. For the uncertainty for activity data of swine, 1% of standard error for swine given in the official *Livestock Statistics* is applied. For activity data for livestock other than swine, uncertainty was substituted by the value for broilers (9%) described in the *Livestock Statistics*. As a result, the uncertainties of the emissions were determined to be -72% to +157% for swine and 51% for buffalo, sheep and goats and horses.

References:

Japan national inventory reports 2003, 2006, 2012, 2018

Y. Fukumoto, *et al. Measurement of NH3, N2O and CH4 emissions from swine manure composting using a new dynamic chamber system,* Proceedings of 1st IWA International Conference on Odor and VOCs Measurement, Regulation and Control techniques. Australia pp 613-620. March 2001

Japan Livestock Technology Association, *GHGs emissions control in livestock Summary*, March 2002

Japan Livestock Technology Association, *GHGs emissions control in livestock Part4*, March 1999

Ministry of Agriculture, Forestry and Fisheries of Japan, *the Project on Survey and Investigation for Elaboration of GHG Emissions from Agriculture, Forest and Fisheries Sector, within the Project on Development for Method of Promotion for Countermeasures of Global Environment in the Agriculture, Forest and Fisheries Sector in FY2011*, 2012

Shibata, Terada, Kurihara, Nishida and Iwasaki; "Estimation of Methane Production in Ruminants": Animal Sciences and Technology, Vol.64, No.8, August 1993

Country inventory case study: India

Overview of India's current Tier 2 approach

India's livestock sector is one of the largest in the world, with more than half of the world's buffalo, more than 10% of all cattle and more than 20% of small ruminants. Livestock have multiple functions in rural livelihoods, and with increasing income and urbanisation, demand for animal products is gradually increasing. India's first and second national communications reported that in 1994 and 2000, enteric fermentation and manure management emissions totalled just over 200,000 GgCO2 (accounting for about 60% of total agricultural emissions).

India has used a country-specific Tier 2 approach for cattle and small ruminant enteric fermentation emissions since submitting its first national communcation in 2004, although the specific method used has changed over time, as described in the second national communication (2012). Methane emissions from manure management are not a key category in the inventory and are estimated using a Tier 1 approach, although applications of the Tier 2 approach have been reported in sources used in the national inventory.

Table 1: Overview of Tiers used for livestock methane emissions in India's national GHG inventories

Livestock types	Tier used for enteric fermentation (CH_4)	Year adopted*	Tier used for manure management (CH_4)	Year adopted*
Dairy cattle	T2	2004	T1	-
Non-dairy cattle	T2	2004	T1	-
Dairy buffalo	T2	2004	T1	-
Non-dairy buffalo	T2	2004	T1	-
Sheep	T2	2012	T1	-
Goats	T2	2012	T1	-
Other livestock	T1	-	T1	-

*Year refers to the year of NC submission

Enteric fermentation

How India's approach has developed over time:

(1) First national communication

In its first national communication, submitted in 1994, India reported emission factors for cattle and buffalo based on the weighted average of emission factors derived through different methods. Cattle and buffalo were divided by breed type, use and age (Table 2). Emission factors were estimated using the IPCC method, by collating published methane emission estimates and by a number of direct measurements using the face mask technique carried out as part of the enabling activities in preparation for compilation of the national communication. Livestock population data derived from the livestock census.

Table 2: Emission factors for different livestock types reported in India's first national communication

Category	Emission factor ($kgCH_4$/head/year)
Dairy cattle	
Indigenous	28±5
Cross-bred	43±5

Non-dairy cattle (indigenous)	
0-1 year	9±3
1-3 year	23±8
Adult	32±6
Non-dairy cattle (cross-bred)	
0-1 year	11±3
1-2.5 year	26±5
Adult	33±4
Dairy buffalo	50±17
Non-dairy buffalo	
0-1 year	8±3
1-3 year	22±6
Adult	44±11

(2) Second national communication

The methodology used in the second national communication is described in a scientific journal publication by Swamy and Bhattacharya (2006). The estimation of gross energy intake is based on dry matter feed intake as stipulated in the Indian Feeding Standards. After defining sub-categories of cattle and buffalo, the annual average live weight for each sub-category was estimated based on national scientific publications. Gross energy intake was estimated as:

$$GE\ (MJ) = (TDNc \times 4.4 \times 4.184 \times 365)/(DE/100)$$

where TDN is total digestible nutrients from the Indian feeding tables. For breeding animals, this included TDN required for maintenance, lactation and pregnancy, while for other animals it includes TDN for maintenance and work.

The researchers who developed this method suggested that a methodology based on Indian feeding standards was more appropriate for estimating gross energy intake than the IPCC method. The Indian feeding standards have been widely accepted within India. They recommend feed rations on the basis of TDN and ME values, and compared to the NRC method are more strongly supported by studies on the nutrition of tropical animals.

Having estimated GE intake for each category of animal, a methane conversion factor was applied to GE intake for each category. The methane conversion factors used were based on IPCC default values but adjusted for younger animal groups based on national research.

In the national inventory, this approach is applied to livestock data at the state level. National level implied emission factors are then the weighted average of emission factors across the country.

Further resources:

India (2004) First national communication. https://unfccc.int/resource/docs/natc/indnc1.pdf

India (2012) Second national communication. https://unfccc.int/resource/docs/natc/indnc2.pdf

Swamy, M., (2016). AFOLU Emissions. Version 1.0 dated July 15, 2016, from GHG platform India: GHG platform India-2007-2012 National Estimates - 2016 Series http://ghgplatform-india.org/data-and-emissions/afolu.html

Swamy M and Bhattacharya S (2006) Budgeting anthropogenic greenhouse gas emission from Indian livestock using country-specific emission coefficients. Current Science 91(10): 1340-1353

Country inventory case study: Ireland

Overview of Ireland's current Tier 2 approach

About 90% of Ireland's agricultural land area is used for grazing or hay and grass silage production. Livestock products account for more than half of the agricultural economy and make major contributions to exports. Until 2006, Ireland's GHG inventory used a Tier 1 approach for all livestock emission sources. Enteric fermentation from cattle and sheep, and cattle manure management are key emission sources. Since 2006 a country-specific Tier 2 approach has been used for enteric fermentation and manure management emissions from cattle.

Table 1: Overview of Tiers used for livestock methane emissions in Ireland's national GHG inventories

Livestock types	Tier used for enteric fermentation (CH_4)	Year adopted*	Tier used for manure management (CH_4)	Year adopted*
Dairy cattle	T2	2006	T2	2006
Non-dairy cattle	T2	2006	T2	2006
Sheep	T1	-	T1	-
Pigs	T1	-	T1	-
Other livestock	T1	-	T1	-

*Year refers to the year of NIR submission

Enteric fermentation

Approach used: Ireland' Tier 2 approach was developed through a commissioned study conducted by the Irish Government under the National Development Plan 2000–2006.[12] The structure of the inventory and quantification approach was specifically designed to capture the diversity of Ireland's grass-fed cattle production systems, and to make use of existing energy balance models used by extension services and farmers in the country.

Livestock characterization and population data: Livestock census data collected by the Central Statistics Office (CSO) categorize the Irish cattle herd into 11 main categories (Table 2). The country was divided into three geographic regions based on slurry storage requirements of local planning authorities and coinciding with the regions used for implementation of nitrogen pollution control measures pursuant to the EU Nitrates Directive. In each region, the length of winter housing and feeding practices vary. Because the CSO livestock statistics do not report numbers for each region, the number of cows in each region was obtained from the Cattle Movement and Monitoring System (CMMS). The total number of cows in the CMMS and CSO data differ, so the proportion of animals in each region in the CMMS data were applied to the total population reported by CSO. Emission factors were calculated for each of the 11 animal categories in each of the 3 regions, and a weighted average across the regions calculated for reporting in the inventory. The CSO undertakes two censuses of animal numbers each year (June, December), and for dairy cows and suckler cows, the average number in each category in June and December is used.

Table 2: Classifications for cattle used in Ireland's national inventory

Cattle type	Classification		
Breeding cattle	Dairy cows	Suckler (beef cows)	
Beef cattle	Male <1 year	Male 1-2 years	Male >2 years

[12] O'Mara (2007), Development of emission factors for the Irish Cattle Herd, www.epa.ie/pubs/reports/research/climate/ertdireport46.html

	Female <1 year	Female 1-2 years	Female >2 years
Other cattle	Breeding bulls	Dairy in-calf heifers	Beef in-calf heifers

Estimation of gross energy intake: For estimation of gross energy intake, Ireland uses a system based on the French energy system (INRA 1989). For each animal type in each region, cattle production systems were characterized in terms of calving date, the dates of winter housing and spring turn-out to grass, milk yield and composition, forage and concentrate feeding level, cow live-weight and live-weight change, and lactation period. Based on these characteristics, the daily energy requirement of cows in each region is calculated by month, including requirements for maintenance, milk yield and composition, foetal growth, and gain or loss of bodyweight.

In the INRA system, net energy requirement is defined in terms of *unites fourragere lait* (UFL), where 1 UFL is the net energy value of 1 kg of barley at 86 per cent dry matter and is equal to 7.11 MJ net energy for lactation (NEl). (For growing beef cattle, net energy requirements are also determined using the same UFL as for dairy, but for finishing cattle, 1 UFV is the net energy value of 1 kg of barley for meat production and is equal to 7.61 MJ NEmg). For dairy cattle, the main equations used in estimation are:

1. Maintenance NEl requirements (MJ) = 9.96 + (0.6 x LW/100), where LW is live-weight. A 10% activity allowance is added for the housed period and a 20 % allowance is added for the grazing period;
2. NEl (MJ) required per kg milk = 0.376 * fat content + 0.209 * protein content + 0.948;
3. Pregnancy: mean of 12.1 MJ NEl /day for the last 3 months of pregnancy;
4. Live-weight change: each kg live-weight lost contributes 24.9 MJ NEl to energy requirements, while each kg of live-weight gained requires 32 MJ NEl.

The live weight of 535 kg for dairy cows was estimated by the Department of Agriculture, Food and the Marine. The composition of the diet of cows in each region was described on a monthly basis, and daily intake was calculated by reference to the daily energy requirement. In estimating diet composition, the concentrate allowance was fixed while forage intake varied according to energy requirements.

Daily methane emissions (MJ/day) were calculated from digestible energy intake using the equation of Yan et al. (2000):

$$CH_4 = DEI * [\ 0.096 + (0.035 \times SDMI/TDMI)\ ] – 2.298 * (FL – 1)$$

where DEI is digestible energy intake (MJ/day), SDMI and TDMI are silage and total dry matter intakes (kg/day), respectively, and FL is feeding level (multiples of the maintenance energy requirement).

A constant methane conversion rate of 0.065 of gross energy intake is applied when the diet consists of grazed grass and 3 kg or less of concentrate supplement per day. This is based on a large New Zealand database of measurements for grazing animals on similar production systems to those in Ireland. Daily CH_4 emissions are summed to give annual emissions for cows in each region, and a weighted national average emission factor is then calculated.

For beef cattle, emissions are determined by calculating lifetime emissions for the animal and by partitioning between the first, second and third years of the animal's life. This approach allows the published CSO animal population census for June to be used directly as the activity data most representative of the inventory year for enteric fermentation while taking into account the movement of cattle from one age category to another (i.e. from 0-1 year old to 1-2 year old to over 2 years old), as enumerated by the June census, up to two times in their three-year lifetime. The most important parameter for beef cattle is live-weight gain, as it directly affects the energy requirement and thus the feed intake. Live-weight gain of different types of cattle was estimated by applying carcass weight of slaughtered cattle from government statistics to the various life stages of each animal category, such that when all categories are combined, that data is consistent with the national statistics for carcass weight (plus or minus 10 kg). Estimation of emissions from beef cattle were directly calculated using the software INRAtion, which is based on the French energy system.

As a result, the emission factors for dairy cattle reported in the NIR vary year to year by tracking milk yield. For other cattle types, the national emission factors vary depending on the average proportion of each animal type in the three regions.

Manure management:

The Farm Facilities Survey (Hyde et al. 2008) provides detailed data on manure management practices to support the adoption of a Tier 2 method for estimating methane emissions from manure management. The Farm Facilities Survey was conducted on a representative sample of farms, the results of which are available at both national level and for each of the three designated Nitrates Directive regions. The partitioning of the year into pasture and housing periods is based on expert opinion in conjunction with the results of the Farm Facilities Survey for each production system identified in the inventory. Having derived the time spent at pasture and the time spent in housing for cattle, the Farm Facilities Survey is used to determine the partitioning of liquid and solid manures to manure management systems within the housing period, and the estimation of the number of animals that are outwintered (i.e. at pasture all year round). The analysis of feeding regime used to estimate enteric fermentation was also used to estimate the excretion of organic matter by cattle. The methane production potential (BO) of manure, and the methane conversion factor (MCF) use the IPCC default values.

Improvements over time: Since the initial adoption of a Tier 2 approach for cattle, Ireland has used the same approach in its inventory. The Department of Agriculture, Food and the Marine has funded the establishment of The Agricultural Greenhouse Gas Research initiative for Ireland (AGRI-I). This is an organisational and collaborative framework designed to: build a critical mass of scientific expertise in GHG research, co-ordinate uniform measurement protocols, and address a specific set of research issues. The AGRI-I network has a specific set of research aims, primarily focussed on the inclusion of validated GHG emissions mitigation strategies into the national inventory. This research include a review of feed intake parameters and assumed nitrogen content of feeds and updates as necessary. A separate but related research project investigated the development of country specific BO and MCF values using a range of cattle manures and environmental conditions. In addition the EPA has funded a research project aimed at reviewing the Tier 2 methodology used for the estimation of CH_4 emissions from cattle.

Further resources:

Ireland (2018) NIR.

O'Mara (2007), Development of emission factors for the Irish Cattle Herd

Hyde et al. (2008), an extensive Farm Facilities (Manure Management) Survey.

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Country inventory case study: The Netherlands

1. Overview of The Netherlands' current Tier 3 and 2 approach

The Netherlands has a strong history in agriculture. Livestock (dairy, swine and poultry), horticulture and arable farming are still major sub-sectors in the country's economy. Key categories in the country's latest inventory include enteric fermentation from dairy cattle, growing cattle and swine. For manure management, methane emissions from cattle, swine and poultry, and N_2O emissions from manure management (direct and indirect following atmospheric deposition of NH_3 and NOx) are key sources. In the Netherlands, methane emissions from enteric fermentation are primarily caused by cattle (89%), followed by swine (6%) and other livestock categories (sheep, goats and horses, 5%).

A country-specific Tier 3 approach is used for enteric fermentation emissions from dairy cattle. A country-specific Tier 2 approach is used for growing and non-dairy cattle, while for all other livestock categories a Tier 1 approach is used and default IPCC emission factors are applied.

Table 1: Tiered approaches used for livestock in the national GHG inventory

Livestock types	Tier used for enteric fermentation (CH_4)	Year adopted*	Tier used for manure management (CH_4)	Year adopted*
Dairy cattle	T3	2006	T2	Before 2003
Growing cattle	T2	Before 2003	T2	Before 2003
Non-dairy cattle	T2	Before 2003	T2	Before 2003
Poultry	NE	Before 2003	T2	Before 2003
Pigs	T1	Before 2003	T2	Before 2003
Other livestock categories	T1	Before 2003	T1	Before 2003

*Year refers to the year of NIR submission, NE=not estimated

Livestock population data originate from the yearly Agricultural census. The census distinguishes a number of livestock categories (Table 2).

Table 2: Livestock categorization method

Mature dairy cattle	2 categories based on region within The Netherlands (Northwest/Southeast)
Mature non-dairy cattle	1 category
Growing cattle	14 categories based on production purpose (replacement or fattening) and age
Swine	6 categories based on age and physiological status
Poultry	9 categories differentiated by production purpose (laying hen or broiler) and age
Sheep	2 categories: ewes and other
Goats	2 categories: milk goats and other
Horses	4 categories: horses and ponies for agriculture or private use
Other animals	Mules and asses, rabbits (does/meat), minks and foxes

Source: Vonk et al. 2018

2. Enteric fermentation emissions from cattle

A Tier 3 approach for mature dairy cattle uses a mechanistic, dynamic model representing fermentation mechanisms in the rumen. Rather than assuming rumen CH_4 production, the model predicts CH_4 production based on the effect of nutrition on microbial activity, volatile fatty acid (VFA) production and hydrogen surplus.

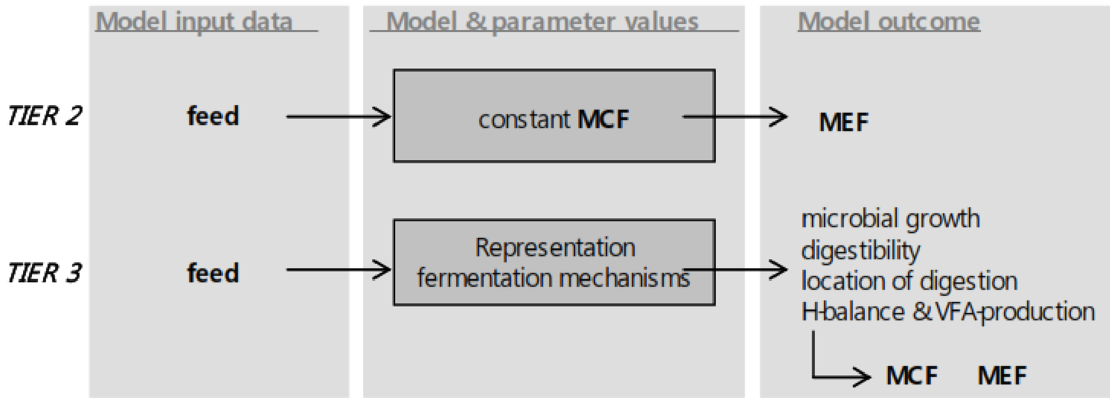
By estimating methane production directly, the model clearly differentiates from other model approaches and calculation methods, and from the Tier 2 approach which uses a fixed methane conversion factor (Figure 1).

The model calculates (i) gross energy (GE) intake, (ii) CH_4 EF (in kg CH_4/cow/year) and (iii) the methane conversion factor (Y_m; % of GE intake converted into CH_4) on the basis of data on:

- The share of feed components (grass silage, maize silage, wet by-products and concentrates);
- the chemical composition of feed components (soluble carbohydrates (including sugars), starch, cell walls (hemi-cellulose, cellulose and lignin), crude protein, crude fat and crude ash);
- rumen intrinsic degradation characteristics of starch, crude protein and fibre.

Due to differences in rations between the Northwest (rations mainly grass-based) and Southeast of the country (large share of maize silage) calculations for these regions are made separately.

Figure 1 Schematic representation of the difference between Tier 2 and Tier 3 approaches (MCF = Methane Conversion Factor, MEF = Methane Emission Factor)



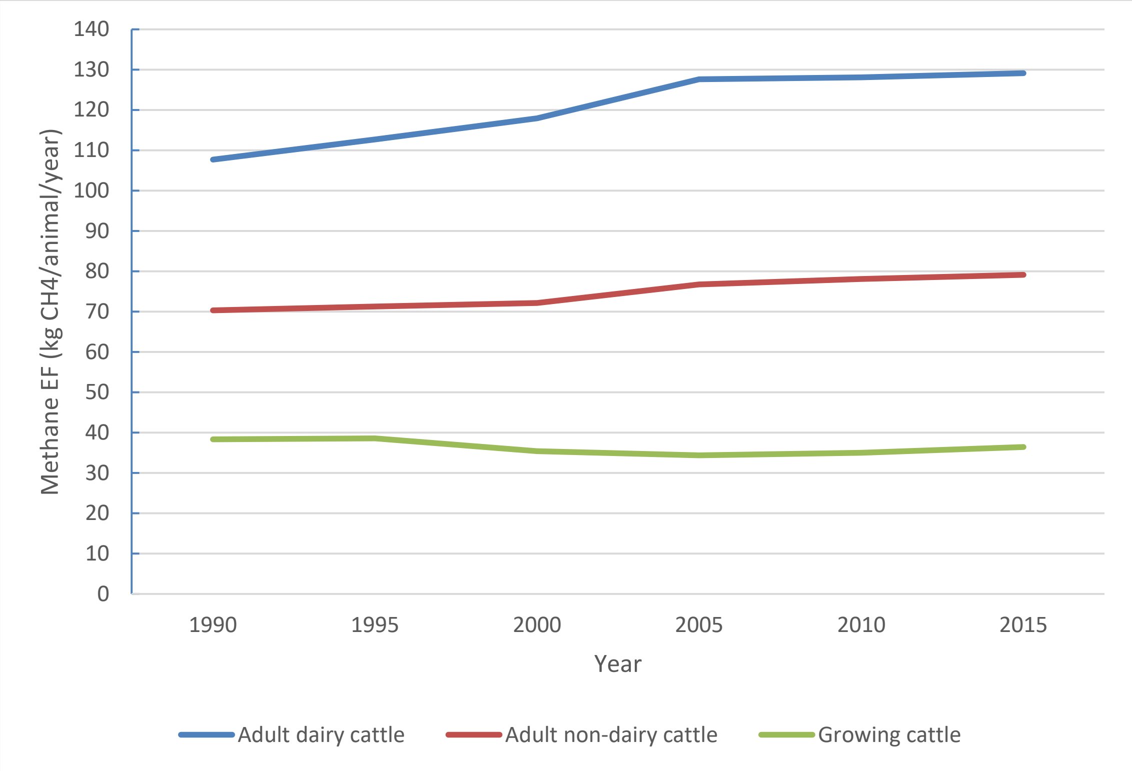
Source: Bannink 2011

For other mature cattle and growing cattle categories, enteric fermentation emissions are calculated by multiplying the gross energy intake with a methane conversion factor (Y_m). As the production of white veal calves is an important sub-sector in The Netherlands, and considering the large share of milk products in their ration, in this case a country-specific Y_m value is used. For all other cattle types (young cattle and mature non-dairy cattle) the IPCC 2006 default Y_m is used.

Gross energy intake is based on rations calculated by the Working Group on Uniformity of calculations of Manure and Mineral data (in Dutch 'Werkgroep Uniformering berekening Mest- en mineralencijfers', WUM). Changes in GE intake are based on changes in both the total feed intake and the share of feed components.

Since 1990, there have been continuous increases in feed intake (20%), level of milk production (34%) and CH_4 emission (17%), resulting in a continued reduction of CH_4 per kg of fat- and protein-corrected milk (13%) (Bannink 2011). An increase in total feed intake has increased the emission factor over time, however a change in nutrient composition, contributing to (among others) feed digestibility has partly offset the increase in emission factor. An overview of emission factors for methane emissions from enteric fermentation is provided in Figure 2.

Figure 2 Methane emission factors for cattle (1990 – 2015)



Source: Netherlands NIR 2017

Inventory compilation

The following data is collected:

- the number of dairy cows;
- registered national milk production;
- a weighed yearly average of feed intake;
- a weighed yearly average of diet composition;
- data on feed analysis and chemical composition of forages, and the composition of concentrates feeds.

Data on nutrition and dairy performance are delivered by the Working Group on Uniformity of calculations of Manure and Mineral data (WUM) on a yearly basis. Data is collected and aggregated by a team under the coordination of Statistics Netherlands (CBS).

Data on the chemical composition of roughages (grass herbage, grass silage, maize silage) are provided by Eurofins Agro, the main commercial laboratory for such in The Netherlands. The chemical composition of roughages from many farms is analysed as part of the Dutch manure policy; farmers in The Netherlands are obliged to demonstrate the mineral management on their farm, including the composition of their roughages (through fixed amounts or by analysis).

Data on the type, amount and chemical composition of by-products and concentrates fed to dairy cattle are collected by CBS by consultation with the feed industry and use of feed tables.

How the approach has developed over time: from Tier 2 to Tier 3 (2006)

The Netherlands began using a country-specific Tier 3 approach for dairy cattle in 2006 to be able to justify a lower CH_4 conversion factor than the average default value with the relatively high nutritional quality of Dutch dairy diets. At that time, the IPCC guidelines for a Tier 2 approach applied a default CH_4 conversion factor of 6.5% of gross energy (GE) intake. This value appeared relatively high for Dutch conditions. Furthermore, using a constant conversion factor did not reflect variation in level of feed intake, feed digestibility and the composition and quality of the ration. A dynamic, mechanistic model to account for this variation was available already (Mills et al., 2001) and was adapted with an improved representation of the production of volatile fatty acids (Bannink et al. 2000; 2006); a crucial element for prediction of hydrogen balance and CH_4 formation. Therefore, the Netherlands revised its method in 2005 by using this dynamic, mechanistic model as a country-specific Tier 3 approach from 2006 onwards.

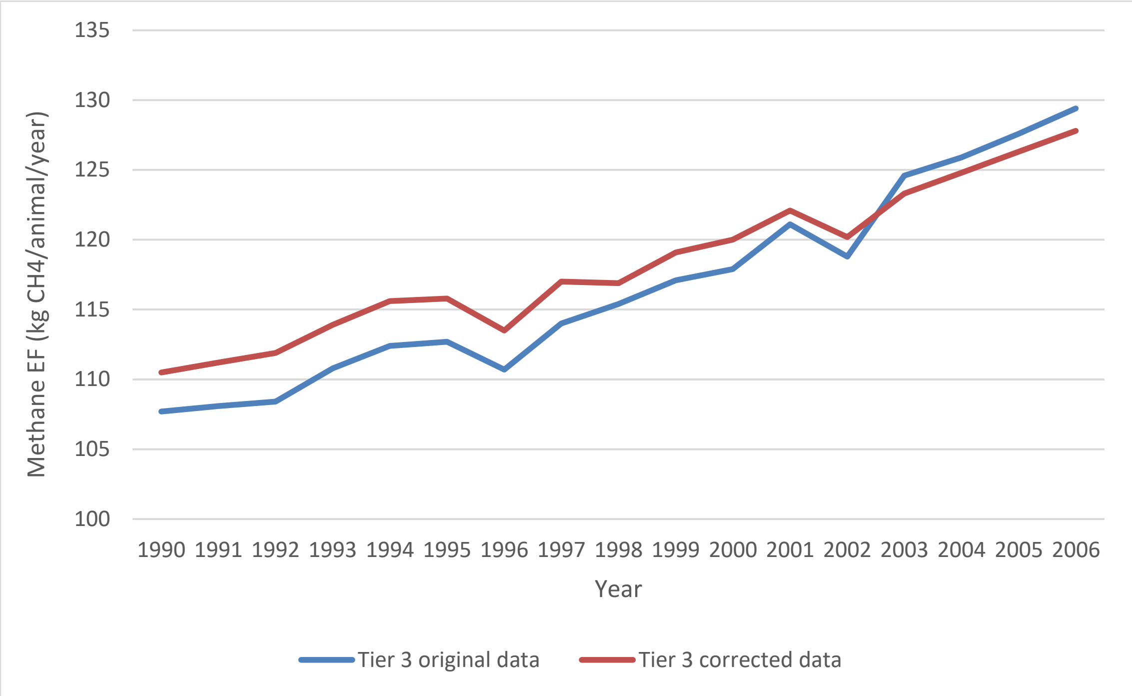
The model is derived from the rumen fermentation model developed by Dijkstra et al. (1992) and extensively evaluated by Neal et al. (1992) and Bannink et al. (1997). The model, initially developed to model the fermentation process in the rumen, appeared to be suitable for methane modelling as well, and offered the opportunity to take more detailed ration composition and quality into account. The model thus enabled more precise methane emission estimations; each aspect of the model is based on scientific research. Evaluation studies by Neal et al. (1992) and Bannink et al. (1997) indicated the need to revise the representation of the amount and type of VFA as end-product of rumen fermentation. Subsequently, a database of in vivo data from lactating cows was developed and analyzed by Bannink et al. (2000; 2006). Mills et al. (2001) adapted the model by adding coefficients for digestion in the small intestine and a mechanistic, adding a dynamic, mechanistic module for microbial activity in the large intestine, and adding calculation of hydrogen balance in rumen and large intestine andCH_4 formation. An updated version with a representation of VFA formation that is dependent on digesta acidity, applied as a Tier 3 approach was described by Bannink et al. (2011).

Revised feed intake, milk production and ration composition data for the years 1990 till 2007 (2009)

In 2009 revisions were made to derive input data on feed intake, ration composition and milk production figures from 1990 until 2007. Revisions included (i) inclusion of feed losses (of roughages, concentrates and by-products), (ii) an increase of the net energy requirement for maintenance and (iii) a correction for the ammonia-N fraction of N in crude protein (Bannink 2011). Calculations of the methane emissions from enteric fermentation from dairy cows were subsequently revised. Results of the corrections are displayed in Figure 3.

In 2016, a slight modification was introduced to let the model apparent faecal N digestibility and excretion urine or ammoniacal N more accurately. This modification had negligible effects on predicted CH_4 emissions however (a 0.03% higher CH_4 emission factor; results not shown).

Figure 3 Recalculated methane EF for dairy cattle with revised input data



Source: adapted from Bannink 2011

4. Methane emissions from manure management

Manure management methane emissions from cattle, swine and poultry are a key category in the national inventory (NIR) and calculated using a country-specific Tier 2 approach. Methane emissions from manure are mainly caused by fermentation of organic matter in an anaerobic environment. As methanogenic bacteria take some time to produce methane, methane from manure stored for less than a month is very low. The conversion of organic matter in methane also depends on manure composition and environmental factors such as temperature. Methane emissions are calculated for liquid and solid manure management systems and, where applicable, also for manure produced on pasture land whilst grazing.

Manure management methane emission estimates are directly related to calculations done for methane emissions from enteric fermentation, as key input data consist of the amount of volatile solids (VS) produced per animal, which are again based on feed intake, composition and VS digestibility. The amount of volatile solids excreted by livestock depends on the digestibility of the organic matter and protein content of the feed. Data on feedstuffs and rations are used to provide this information (Zom and Groenestein 2015).

Manure management methane emissions are calculated by multiplying the volatile solids excretion (VS, in kg) with the maximum methane production potential (B_0, in m^3 CH_4/kg VS) and the methane conversion factor, which is based on the manure management conditions.

For all other livestock categories emissions are estimated using a Tier 1 approach (Vonk et al. 2018).

5. Uncertainty management

The uncertainty for each aspect of the rumen fermentation model used to calculate methane emissions from enteric fermentation, is estimated by experts. Since revisions to derive input data were done in 2009, and calculations were corrected in 2011, the estimated uncertainty for annual emissions from dairy cattle was corrected from 20 to 16%.

Until 2017, a 5% uncertainty level for livestock population data was used, while for the emission factor an uncertainty level of 15% was employed (combining to 16% overall uncertainty).

In the recently published update of the methodology for estimating emissions from agriculture in The Netherlands, a revised uncertainty level for mature dairy cattle of 15% is described, based on a new estimate of uncertainty of 2% for the total animal population. Furthermore, uncertainty levels are disaggregated for the Northwest and Southeast of The Netherlands, with an uncertainty of 21% for the split emission factor, and 3.4 and 2.4% for the activity data, respectively.

For other mature cattle, growing cattle, swine and other livestock categories, uncertainty levels are 21, 11, 41 and 44.5% respectively (Vonk et al. 2018).

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Country inventory case study: New Zealand

Overview of New Zealand's current Tier 2 approach

Grassland-based animal husbandry makes major contributions to New Zealand's economy, and production practices and productivity have changed considerably in recent decades. Key categories in the latest inventory include enteric fermentation emissions from dairy cattle, non-dairy cattle, sheep and deer; manure management methane emissions from dairy cattle, and direct N_2O emissions from urine and dung deposited by grazing animals (NIR 2017). New Zealand currently reports emissions from dairy and non-dairy cattle, sheep and deer using Tier 2 approaches (Table 1). A country-specific Tier 1 emission factor is used for goats and the IPCC default is used for pigs, as these emission sources are not significant. New Zealand began using a country-specific Tier 2 approach for livestock enteric fermentation in the early 1990s. Initially, static emission factors were used that did not change along with changes in production practices or animal performance. Since 2003, a full Tier 2 approach has been adopted in which enteric fermentation emissions per head per year vary according to changes in production practice and animal performance.

Table 1: Overview of Tiers used for livestock methane emissions in New Zealand's national GHG inventories

Livestock types	Tier used for enteric fermentation (CH_4)	Year adopted*	Tier used for manure management (CH_4)	Year adopted*
Dairy cows	T2	2003	T2	2006
Beef cattle	T2	2003	T2	2006
Sheep	T2	2003	T2	2006
Goats	CS T1	1994	T1	-
Deer	T2	2003	T2	2006
Pigs	T1	-	T1	-

*Year refers to the year of NIR submission

Enteric fermentation

Approach used: Since 2003, New Zealand has used country-specific approaches to estimate enteric fermentation emissions from the major ruminant livestock categories. Because country-specific data and monthly data intervals are used for livestock populations, productivity and pasture quality, the approach may be considered to be close to a Tier 3 methodology.

How the approach has developed over time: New Zealand's livestock emissions inventory has undergone three distinct phases of development.

(1) 1994 – 2001: Tier 1/ Tier 2 approach

Even before the IPCC 1996 Guidelines were released, New Zealand was reporting livestock emissions using a country-specific approach similar to the approaches later set out in the IPCC Guidelines. In 1990, the Ministry for the Environment commissioned an inventory of enteric methane emissions (Ulyatt et al. 1991). The resulting inventory estimated methane emissions as:

Methane output = livestock number x intake x emission per kg of intake.

To implement this, the commissioned study used national statistics on livestock populations together with a livestock population model to estimate the number of animals in sub-categories of each type of ruminant on a monthly time-step by accounting for births, deaths, the month of slaughter and age. Feed intake was estimated for four separate regions of the country to account for differences in pasture quality in different climatic regions (defined on the basis of temperature and rainfall distribution) and for three pasture types within each region (i.e., improved, unimproved, tussock). Published and unpublished data and expert opinion were used to characterize the energy density and chemical composition of the diet consumed in each month by each sub-category of livestock. Dry matter intake was estimated on the basis of energy requirements and the data on diet quality. Methane emissions per unit of dry matter intake were then estimated using a theoretical model of rumen digestion (Baldwin et al. 1987).

When the inventory model developed by Ulyatt et al. (1991) was incorporated into the national GHG inventory, however, a simplified approach was used in which:

methane output = livestock number x methane emission factor

where the methane emission factor was taken from the study by Ulyatt et al. (1991). Thus, while the Ulyatt et al. (1991) method was a Tier 2 approach, the national inventory used a Tier 1 approach with a country-specific emission factor that remained fixed over time.

In 2001, a review was commissioned to assess the conformity of the inventory approach to the IPCC 1996 Guidelines and to suggest recommendations for improving the inventory. The main findings of the review (Clark 2001) included the following:

- Use of a fixed emission factor resulted in underestimation of emissions, because changes in animal performance were not reflected in the emission factor. A comparison for 1998 of the official inventory estimates and an inventory using methane emission factors adjusted for productivity gains indicated underestimation by official inventory by about 7%.
- The Baldwin model gave estimates of methane output per unit of feed intake of around 7.5% of gross energy, compared to 6% of gross energy for country-specific experimental data and the IPCC default value.
- The contribution to accuracy of dividing the country into climatic regions was limited, whereas if the country were divided into regions based on industry definitions, animal performance data would be readily available and could be more frequently updated.
- Areas of non-conformity with the IPCC Guidelines included the use of a Tier 1 approach in the national inventory when livestock emissions were among the key source categories; lack of transparent documentation of the inventory methods used; and lack of uncertainty analysis.

(2) 2003 – 2008: developing and implementing a Tier 2 / Tier 3 approach

Following the 2001 review, a revised inventory model was developed that differed from the former approach in five main respects:

(i) The revised model did not use fixed emission factors but calculated emissions using a monthly time step model containing data on livestock numbers, livestock performance and diet quality.

(ii) The input data on livestock performance characteristics change each year in line with published industry and government information, thus accounting for changes in livestock productivity.

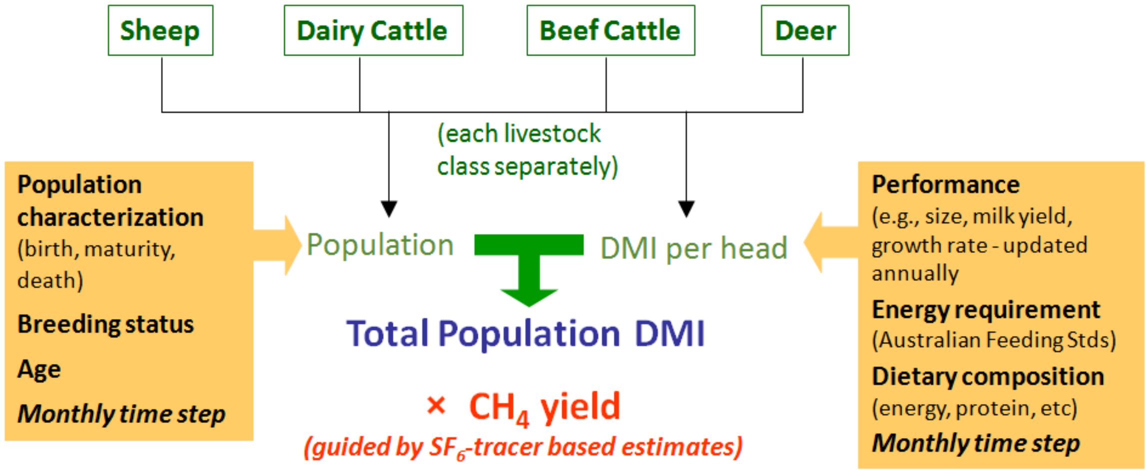
(iii) Data on direct measurements of methane emissions from ruminants collected in New Zealand were used to estimate the conversion of energy intake to methane output.

(iv) The size of the errors in the inventory were assessed using Monte Carlo analysis; and

(v) The inventory method was transparently documented (Clark et al 2003).

The overall approach is summarized in Figure 1.

Figure 1: Overall approach in New Zealand's revised Tier 2 inventory approach



Source: NIR (2007)

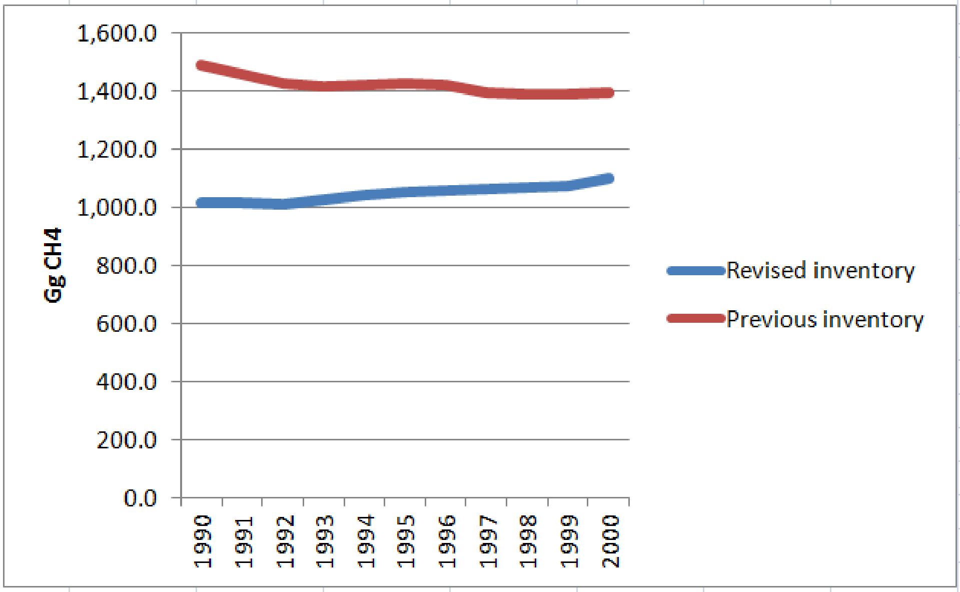
For each type of ruminant (dairy cattle, beef cattle, sheep and deer), a population model incorporating births, deaths and slaughter, was developed to estimate the number of animals in each sub-category, including numbers of pregnant and lactating animals on a monthly basis. Livestock productivity data was used along with a model of energy requirements and data on dietary composition of forage and feed to estimate monthly dry matter intake per head for each sub-category of animal. Because of a lack of routine representative surveys in the country, the best available data was used. The same data sources were used in each year, so that even though there are uncertainties around the values used each year, the uncertainties are likely to be consistent, and a time series that reflects changing farming practices is provided. Data sources and values were transparently documented, so that the values used could be incrementally improved over time.

To estimate DMI for each sub-category, the energy required to meet the assumed levels of performance (MJ metabolisable energy (ME) per day) was divided by the energy concentration of the diet consumed (MJ ME per kg dry matter). To estimate energy requirements, an Australian model (CSIRO 1990) was used in preference to IPCC or other models because the Australian model had been developed specifically for grazing animals, which more closely reflects New Zealand's predominant production practices. Monthly data on the ME value of forage from scientific publications was entered into the model, assuming the same monthly values for all years, as there was no historical time series.

To convert energy intake into methane output, none of the existing published models were judged to be appropriate. However, since 1996 SF_6 tracer techniques had been used to measure methane emissions in New Zealand, and by 2003 New Zealand had one of the largest datasets of methane emission measurements under grazing conditions. For the initial revised inventory, the averages of existing published and unpublished measurements for different types of animal were used.

Using the revised inventory model, enteric fermentation emissions were estimated for 1990 – 2000. The estimate for 1990 submitted in NIR 2003 was 47% lower than in the previously submitted inventory estimates for that year (Figure 2). And while the previous inventory had shown a decreasing trend in total enteric fermentation emissions, the revised inventory showed a lower, but increasing trend. The resulting re-estimate of the trend in enteric fermentation emissions was of great significance, as at that time New Zealand was preparing for the first commitment period of the Kyoto Protocol.

Figure 2: Trend in enteric fermentation emissions (1990-2000) using the initial and revised inventory approaches



Source: NIR 2003

(3) 2009 – present: continuous improvement of Tier 2 / Tier 3 approach

Since 2009, the structure and overall approach used in the national inventory has largely remained unchanged. Improvements have focused on improving the accuracy of inventory estimates, improvements in operational efficiency, and improvements in inventory quality. To facilitate regularization of the continual improvement process, in 2009 an Agricultural Inventory Advisory Panel was established consisting of representatives of the Ministry for Primary Industries (MPI) and Ministry for the Environment, which together are responsible for the inventory compilation and reporting; research institutes; and experts on methane and nitrous oxide emissions. The panel provides advice on proposed changes to the agricultural section of the national GHG inventory on the basis of peer reviewed reports and papers (see Inventory Practice: New Zealand Advisory Panel).

For livestock emission sources in the inventory, significant changes have included the following:[13]

Regionalisation of dairy sector emissions: Before 2010, CH_4 and N_2O emissions from ruminants were disaggregated by species and sub-categories of animal based on age and breeding status but not by region. This was because (a) the 2001 inventory review (Clark 2001) indicated that disaggregating the inventory by climatic region led to identical results to a simpler national model; and (b) some key data (e.g. animal weight, animal performance) was not available on a regional level for all species. However, for dairy cattle, a time series of regionally disaggregated data on dairy cattle populations, live weight, milk yield and milk fat and protein contents was available. Moreover, emissions from the dairy sector had increased from 25% of total agricultural emissions in 1990 to almost 40% of agricultural emissions in 2006, and the regional structure of the sector had changed considerably, suggesting that a single national model may no longer be the most accurate way of estimating GHG emissions from the sector. A comparison of national emission estimates based on a single national model and the aggregation of 17 sub-national estimates indicated that a regional approach has little impact on 1990 emission estimates but reduced estimates for 2006 by 2.3%. The regionalised approach for the dairy sector was adopted in NIR 2010.

Improvements in animal live weight estimates: New Zealand's methane emissions model estimates emissions on the basis of estimated energy and feed intakes. Since most energy consumed by breeding animals is used for maintenance, animal live weight is closely related to energy and feed intake estimates. Feed intake is

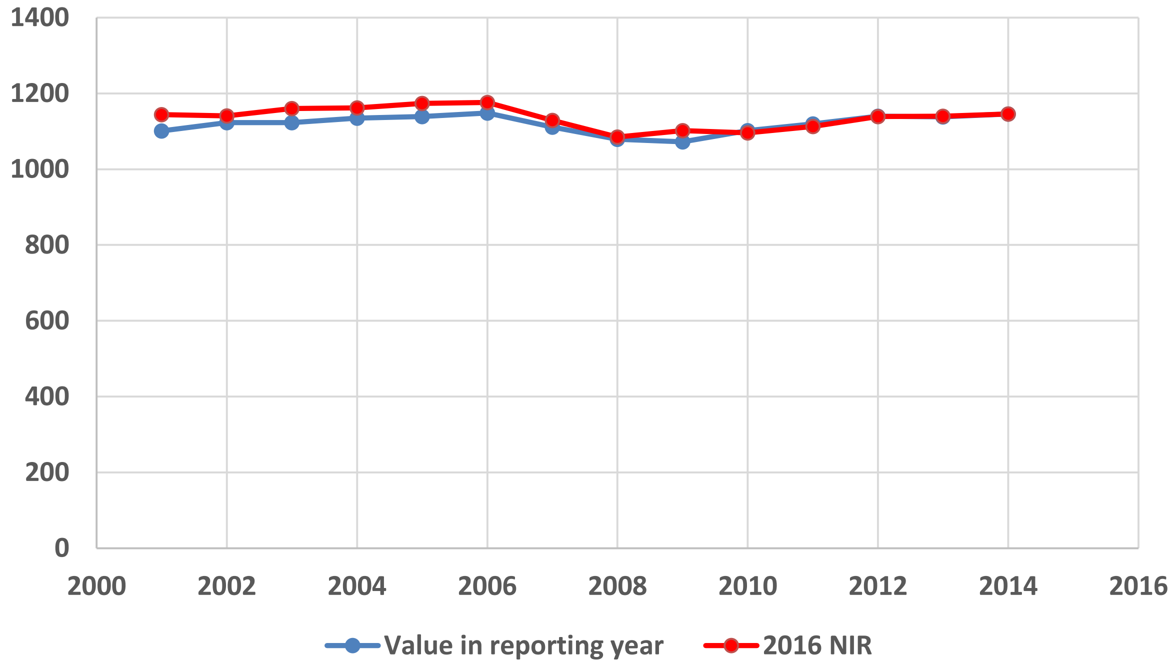
[13] Clark (2018) *Key steps and requirements in moving to an advanced inventory: Experience from New Zealand.*

estimated on the basis of live weight, but estimation of live weight in the inventory model is done using data on carcass weight and an assumed carcass ratio (i.e. dressing out percentage). A review of the national inventory model (Muir *et al.,* 2008) suggested that the ewe and beef cow carcass or live weight estimates and carcass ratios used in the model were based on limited data and assumptions that might lead to significant errors in the inventory estimates. A review of the best available published and unpublished data and collection of new primary data led to revision of the time series for live weight estimates for ewes and beef cows. (See Inventory Practice: Improved Estimates of Live Weight in New Zealand).

Adjustments to animal population models: Data on total population of each livestock type in New Zealand is available, but the inventory uses a population model to estimate change in the populations of sub-categories of each type based on age and breeding status. The estimated sub-populations are not directly verifiable. Therefore it is important to check the suitability of the assumptions used in the model. A review of the population model was commissioned, which led to recommendations to revise various assumptions, such as the dates of lambing / calving and slaughter for certain sub-categories, mortality rates and average age at slaughter. These adjustments were recommended on the basis of the best available data. In addition, improvements have been made to the software used for inventory compilation and to the procedures for error checking and recalculation.

These adjustments and the resulting recalculations have led to marginal changes in estimated total emissions (Figure 3).

Figure 3: Comparison of total enteric fermentation emissions in NIR 2016 submission and previous submissions



Source: H. Clark (2018)

Manure management (Methane)

Manure management methane emissions from dairy cattle are a key category in the national inventory (NIR 2017).

Approach used: Because most livestock production in the country is grazing-based, whereas other approaches are more suited to systems involving storage of manure, since 2006 a country-specific approach to estimating manure management methane emissions has been used. Since NIR 2015, for methane from dairy effluent in anaerobic lagoons, the equations in the IPCC 2006 Guidelines have been used.

Description of approach: The country-specific approach is based on methods recommended by Saggar et al (2003) in a review commissioned by the Ministry of Agriculture and Forestry. The approach involves:

(1) estimating the total quantity of excreta produced,

(2) partitioning the excreta between that deposited directly onto pastures and that stored in anaerobic lagoons; and

(3) applying country-specific emission factors for the quantity of methane produced per unit of faecal dry matter produced.

Faecal dry matter output is calculated monthly for each species subcategory as:

$$FDM = DMI \times (1-DMD)$$

Where:

FDM = faecal dry matter output
DMI = dry matter intake
DMD = dry matter digestibility

DMI and DMD are the same as in the enteric methane inventory, and:

$$M = (FDM \times MMS) \times Ym$$

where:
M = methane from manure management
FDM = faecal dry matter output
MMS = proportion of faecal material deposited on pasture
Ym = country specific methane yield methane yield (g CH_4 per year)

95 percent of excreta from dairy cattle and all excreta from other ruminants is deposited directly on pastures. Values for Ym for excreta deposited on pastures for sheep and cattle are obtained from country-specific measurement studies. For deer, there have been no specific measurements, so the mean of cattle and sheep values is used. As improvements in the national inventory have been implemented (e.g. changes in livestock performance parameters, regionalization of the dairy inventory), these changes have been incorporated into the data used to estimate manure management methane emissions.

Only 5% of dairy cattle manure is stored in anaerobic lagoon waste systems, for which the method adopted from 2006-2015 was as follows:

$$M = (FDM \times MMS) \times W/1000/d \times Ym$$

Where:
M = methane from manure management
MMS = proportion of faecal material deposited on pasture
W = water dilution rate (litres per kg faecal dry matter)
d = average depth of a lagoon (metres)
Ym = methane yield (g CH_4 per m^2 per year)

The method adopted assumed that all faeces deposited in lagoons are diluted with 90 litres of water per kilogram of dung dry matter, which gives the total volume of effluent stored (NIR 2008). Published reports estimated annual CH_4 emissions as 0.33–6.21 kg CH_4/m^2/year from anaerobic lagoons in New Zealand, and the mean value is assumed in the inventory. From NIR 2015, this method was replaced by the IPCC 2006 Tier 2 equations in response to criticism of the country-specific methodology in scientific papers published by New Zealand researchers and a review commissioned by MPI (Pratt et al 2012).

Uncertainty management

Prior to revision of the inventory approach in 2003, New Zealand's inventory submissions did not provide a quantitative estimate of uncertainty. Uncertainty assessment was conducted as part of revision of the livestock inventory, and was reported in the 2003 NIR submission. The assessment used Monte Carlo analysis to assess the uncertainties in predicted outputs (i.e. dry matter intake and methane emissions) and to determine confidence intervals around the estimated output values. This analysis was implemented in a specialized software package, @RISK. In Monte Carlo analysis, input parameters that are subject to uncertainty (in this case, energy intake, energy concentration in the diet, the quantity of methane produced per unit of intake and the number of animals) are described as probability distributions rather than single values. The model is then run thousands of times, with a new value for each input parameter sampled from within its probability distribution. The resulting estimated emissions thus reflect the range of assumed variability in the input parameters. The contribution of each input parameter to uncertainty in the output estimates is then quantified using regression analysis.

Initially, analysis was applied to the inventory years 1990 and 1998. Results estimated uncertainty in methane emissions of 23.5% (Clark et al. 2003). It also showed that the 95% confidence intervals for 1990 and all subsequent years overlap, so that from a statistical perspective, it was not certain that emissions had actually changed since 1990. Analysis also showed that uncertainty in methane emissions was dominated by the uncertainty in the methane per unit of intake, with smaller contributions from uncertainties in the estimates of energy requirements and pasture quality. Therefore, reducing uncertainties in methane emissions per unit of intake would have the greatest contribution to reducing uncertainty in the overall livestock methane inventory.

In subsequent years, the uncertainty of the annual estimate was calculated using the 95 percent confidence interval from the Monte Carlo simulation as a percentage of the mean value, i.e. in 2001, the uncertainty in annual emissions was ± 53 percent (Table 2). The uncertainty in annual estimated livestock methane emissions was about 12% of total national emissions, and was the largest source of uncertainty in the whole inventory. However, assuming that uncertainty between years is correlated, the contribution of livestock methane emissions to uncertainty in the trend in emissions was only about 2.4%.

Table 2: Uncertainty in the annual estimate of enteric fermentation emissions for 1990, 2001 and 2005 estimated using Monte Carlo simulation (1990, 2001) and the 95% confidence interval (2005)

	Enteric methane emissions (Gg/year)	95% CI minimum	95% CI maximum
1990	1015.5	478.1	1552.9
2001	1099.4	517.6	1681.2
2005	1139.0	536.2	1741.8

Source: NIR 2007

In 2009, the Ministry of Agriculture and Forestry commissioned a new study to recalculate the uncertainty of the enteric fermentation methane emissions for sheep and cattle (Kelliher et al, 2009). Since the uncertainty analysis in 2003, a larger number of experimental estimates of feed intake and methane yield was available (529 in 2009, compared to 50 used in the 2003 analysis), providing an opportunity to re-estimate uncertainty in the inventory. In addition to estimating uncertainty in total methane emissions, the study also addressed other questions, such as the relationship between age of sheep or cattle and methane yield. It concluded that there were no statistically significant differences between methane yields of sheep or cattle of different ages, and estimated the number of additional methane yield experiments and measurements that would be required to reduce uncertainty in the livestock methane inventory by 1%. Overall uncertainty in the livestock methane inventory was estimated at 16%. Thus, uncertainty analysis contributed not only to producing a new estimate of total uncertainty in the inventory, but also improvements in methods for uncertainty analysis, providing guidance on input data values, and support to refining future inventory improvement activities.

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Country inventory case study: Sweden

Overview of Sweden's current Tier 2 approach

The cattle industry in Sweden has, as in other developed countries, undergone large changes in structure and intensity in recent years. Numbers of dairy farms and animals have decreased, but the total production of milk has remained stable due to increasing milk production per cow. Today most farmers produce the forage for cattle feeding themselves but concentrates are often bought from feed companies. Changes have also occurred in feed evaluation and diet formulation methods.

Enteric fermentation emissions from dairy and non-dairy cattle, sheep and horses, and manure management methane emissions from non-dairy cattle are key categories in the national inventory. Sweden has used a country-specific Tier 2 approach for enteric fermentation from dairy and other cattle since the late 1990s. The approach used was updated in 2016. A Tier 1 approach is used for other livestock types (Table 1).

Table 1: Overview of Tiers used for livestock methane emissions in Sweden's national GHG inventory

Livestock types	Tier used for enteric fermentation (CH_4)	Year adopted*	Tier used for manure management (CH_4)	Year adopted*
Dairy cattle	T2	1990s	T2	1990s
Non-dairy cattle	T2	1990s	T2	1990s
Sheep	T1	-	T1	-
Pigs	T1	-	T2	1990s (later discontinued)
Horses	T1	-	T1	-

*Year refers to the year of NC submission

Livestock characterization: Table 2 shows how livestock are categorized for estimation of different emission sources. Livestock population data comes from the Farm Register administered by the Swedish Board of Agriculture and Statistics Sweden. The register collects population data in mid-June of each year and this is taken to be the annual average. The Farm Register does not include data on the distribution of calves older and younger than 6 months. The inventory therefore assumes that 60 % are younger than 6 months and the rest are over 6 months old.

Table 2. Livestock subgroups used in Sweden's inventory

Categories according to IPCC Guidelines	Sub-categories Enteric Fermentation	Sub-categories Methane from manure management	Sub-categories N_2O from manure management	Sub-categories N_2O from grazing animals
Dairy Cattle	Dairy cows	Dairy cows	Dairy cows	Dairy cows
Non-Dairy Cattle	Beef cows	Beef cows	Beef cows	Beef cows
	Other cattle	Growing animals (12-24 months)	Growing animals (12-24 months)	Growing animals (12-24 months)
		Calves > 6 months	Calves > 6 months	Calves > 6 months
		Calves < 6 months	Calves < 6 months	Calves < 6 months

Source: NIR 2003

Enteric fermentation

Sweden's approach for enteric fermentation estimates has developed over time.

(1) 1990s and early 2000's

In the 1990s and early 2000s, Sweden's inventory used a country-specific methodology to estimate feed energy requirements and emission factors for cattle.[14] The main difference with the IPCC model is that the Swedish model used metabolisable energy as opposed to gross energy intake. Furthermore, the energy loss through methane emissions is calculated as a fraction of digestible energy. This fraction is determined by total feed intake and digestibility of the feed, and therefore varies with diet, whereas the IPCC expresses feed energy content as a constant fraction of gross energy in feed.

The energy requirements for maintenance, growth, lactation and pregnancy are estimated in terms of metabolisable energy (MJ/day).[15] This is then converted to digestible energy using an expression from Lindgren (1980):

$$\textit{Metabolisable energy (\% of digestible energy)} = 83{,}2 + 2{,}53 * L - 0{,}045 * G - 0{,}184 * Rp,$$

where L is the total feed intake expressed as a multiple of maintenance energy, G is the share (%) of roughage in the feed and Rp is the crude protein concentration (%) of the feed. Digestible energy is then used to calculate the methane conversion rate as:

$$\textit{Methane conversion rate (\% methane in digestible energy)} =$$

$$15{,}7 - 0{,}030 * SK - 1{,}4 * L,$$

where SK is the digestibility of the feed (% of gross energy) and L is the total feed intake expressed as a multiple of maintenance energy. The emission factor can be calculated as:

$$\textit{Emission factor (kg } CH_4\textit{/head and year)} = (DE * Ym / 55{,}65) * 365$$

where DE is the digestible energy (MJ/head and day) and Y_m is the methane conversion rate (% of digestible energy). For dairy cows the calculation is performed for a lactation period of 305 days and a non-lactating period of 60 days, which are summed to give the annual CH_4 emission per animal.

To implement this methodology, milk yield data was used together with national feed tables to estimate the key parameters describing diet composition and quality. Data on milk yields came from the trade organisation Swedish Milk, as reported by their supplier farmers who use a production evaluation tool to optimize production. This database covers about 80% of dairy farmers. Farmers not linked to Swedish Milk are assumed to have a lower productivity because the main reason for keeping cows is not commercial production. Milk yield data were then used together with the national feed tables that underlie the production evaluation tool to estimate diet components and diet quality.

(3) 2017 onwards

In 2016, the Swedish Environmental Protection Agency commissioned a review of the inventory methodology for cattle enteric fermentation emissions by an expert at the Swedish University of Agricultural Sciences (Bertilsson 2016). This revision considered that most feed farmers and advisers were by now using a specific software for cattle diet formulation, NorFor (http://www.norfor.info/; Volden, 2011). NorFor uses a net energy system rather than a metabolizable energy system, and its internal equations were developed on the basis of feed trials carried out over many years throughout Scandinavia. NorFor in fact automatically calculates enteric methane production from data input by farmers. For dairy cows, it uses an equation published by Nielsen et al. (2015):

[14] Lindgren 1980, Murphy 1992, Bertilsson 2001

[15] Spörndly 1999

$$CH_4 \text{ (MJ/cow/day)} = 1.39*DMI - 0.091*FA$$

where

DMI = Dry Matter Intake, per cow and day

FA = Fatty Acids (g/kg DM in total feeds)

In the NorFor package GE is calculated according to Volden (2011). For the energy content in feed, a value of 18.4 MJ/kg DM is taken for grain-based concentrate, and 20.0 MJ/ kg DM for grass silage. The final value used depends on the proportions of concentrate and silage in the diet. For dairy cattle, feed consumption estimates are based on the recommendations in metabolisable energy as given in the national feed tables. The nutritional values of forages are according to data collected in the NorFor programme.

The live weight of cows is assumed to be 650 kg, based on research herds in the country. Average milk production is calculated from milk delivered to the dairies and on-farm consumption, i.e. total milk output divided by the number of dairy cows. Data on actual feeding practices are not widely available, so the inventory used the standard diets contained in web-based advisory packages that are widely used by farmers, as well as published surveys and others concerning feeding of cattle.

The values calculated (e.g. 141 kgCH_4 / head/year) were compared with values reported in nearby countries, such as Norway and Denmark.

Table 2: Data sources used in estimation of dairy cattle methane emissions

Parameters	Data sources
No. of dairy cows	Federation of Swedish farmers
Milk delivered to Swedish dairies	The Swedish Board of Agriculture
On farm consumption (5.6%)	Federation of Swedish farmers
Total milk production including home consumption	Calculated
Milk, kg/cow/year	Calculated
Fat,%	Federation of Swedish farmers
Protein,%	Federation of Swedish farmers
ECM, kg/cow/year	Calculated
ECM, kg/cow/day	Calculated
Total energy requirements, MJ ME for maintenance, milk production and pregnancy, Per cow and day	National feed tables
Silage, MJ ME/kg DM	National feed tables
Concentrate, MJ ME/kg DM	Expert judgement
Silage fatty acids (FA), g/kg DM	NorFor
Concentrate FA, g/kg DM	NorFor
Forage proportion, %DM	Expert judgement
MJ ME/kg total feeds in diet	Calculated
FA, g/kg DM total feeds	Calculated
Dry Matter Intake (total), kg DM/cow/day	Calculated
MJ GE/cow/day	Calculated
CH_4, MJ/day	Calculated
CH_4, g/day	Calculated
YM, %GE	Calculated
CH_4, kg/cow/year	***Calculated***

Source: Sweden NIR 2017

Manure management

In the late 1990s, the IPCC Tier 2 methodology was applied to methane manure management emissions from cattle and pigs. The maximum methane production potential (Bo) and methane conversion factor (MCF) used IPCC default values, except for MCF for liquid manure, where a value of 10 % was adopted as it was considered to be more appropriate for Swedish conditions with its cold climate and because the slurry containers usually have a surface cover.

Data on manure production from cattle and pigs came from the Swedish Board of Agriculture, which had carried out large-scale experiments that determined the amount of manure produced per animal. The same value is used every year, except for dairy cattle, where manure production was assumed to be related to milk production, so the trend in manure production is extrapolated based on the trend in milk production

Data on waste management systems derived from nationally representative surveys of fertilizer and animal manure used conducted by Statistics Sweden every two years. For intervening years, interpolated values are used.

Further resources:

Sweden national inventory reports 2003, 2014, 2016, 2017

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Country inventory case study: United Kingdom

Overview of UK's current Tier 2 approach

The UK reports emissions from three cattle categories. It uses a Tier 2 approach for dairy cows and beef cows, and a Tier 1 approach for all other cattle (Table 1). A Tier 1 approach is used for all other livestock. For lambs, the UK has adjusted the Tier 1 IPCC default factor to UK conditions. Total emissions from enteric fermentation, enteric fermentation from cattle and enteric fermentation from sheep, and methane and nitrous oxide emission from manure management are identified as key categories in the latest inventory (NIR 2017). NIR 2018 used a thoroughly revised, country-specific Tier 2 approach for cattle.

Table 1: Overview of Tiers used for livestock methane emissions in the UK's national GHG inventories

Livestock types	Tier used for enteric fermentation (CH_4)	Year adopted*	Tier used for manure management (CH_4)	Year adopted*
Dairy cows	T2	2003	T2	2003
Beef cows	T2	2003	T2	2003
Other cattle	T1	-	T2	2003
Sheep	T2(T1)**	2003**	T2	2003
Pigs	T1	-	T1	-
Other	T1	-	T1	-

*Year refers to the year of NIR submission; ** Later discontinued, then re-adopted in NIR 2018.

Enteric fermentation

Until 2018, the UK used the IPCC model to estimate enteric fermentation emissions from dairy and beef cattle. In NIR 2018, the results of commissioned research were incorporated in the inventory, which now uses a country-specific method.

(1) Approach used until 2017

Until 2018, the UK implemented the IPCC Tier 2 model for dairy and beef cows. The approach estimates daily gross energy (GE) intake on the basis of animal performance, management practices and environmental factors. GE is converted to methane using a methane conversion factor (Ym), and estimated daily emissions are multiplied by number of days to make an estimate of annual emissions per head. Activity data on population of livestock of each category are multiplied by the EF to estimate total annual emissions from enteric fermentation for that category of livestock. An innovation in the UK's implementation of the IPCC model is the use of a country-specific method for estimating feed digestibility, which it has used since NIR 2005 (see Inventory Practice UK's country-specific method for estimating digestibility). This innovation used a country-specific energy balance model, the use of which was expanded in the country-specific methodology adopted in 2018.

Activity data: Livestock population data is provided each year from the Department of Environment, Food and Rural Affairs (DEFRA). This data is compiled from results of the agricultural census conducted in June every year by the devolved administrations (i.e. England, Wales, Scotland and Northern Ireland), which use the same livestock sub-categories to enable summation to UK population totals.

Emissions were separately estimated for breeding dairy cows, beef cows and six other types of cattle (Table 2). For dairy cows, until 2004 the dairy herd was defined as cows and heifers in milk plus cows in calf but not in milk. [16] In 2005, the dairy herd definition was changed to 'cows over two years of age with offspring', which does not include cows in calf but not in milk. Until NIR 2013, 'other cattle' included dairy heifers, beef heifers,

[16] https://www.gov.uk/government/statistical-data-sets/agriculture-in-the-united-kingdom

others>2 and others 1-2 years old. This was later expanded to 6 categories (see Table 2) to better account for the different characteristics of dairy and beef animals (NIR 2013).

Table 2: Livestock categorization in the UK's Tier 2 approach 2013-2017

Dairy cows	Beef cows	Other cattle
1 category ('dairy breeding herd' which is defined as dairy cows over two years of age with offspring)	1 category	6 categories: dairy heifers, beef heifers, dairy replacements > 1 year, beef all other > 1 year, dairy calves < 1 year, beef calves < 1 year

Animal performance data needed for IPCC model equations:

Dairy cows: For dairy cows, the UK used country-specific data for dairy cow live weight, milk yield, milk fat content, feed digestibility and activity (proportion of the year spent grazing), each of which varies from year to year. The estimated EF thus tracks change in management practice and animal performance on an annual basis. All other parameters used IPCC default values. See Table 3.

In early NIR submissions, the UK estimated dairy cow live weight by assuming a 1% annual increase compared to the figure for 1990. In NIR 2008, the data source and method used to estimate live weight changed to use data from a carcass weight survey adjusted for a carcass ratio of 0.48. Since the BSE crisis in the 1990s, slaughter must take place at designated facilities, and monthly surveys are undertaken of numbers animals (by sub-category) slaughtered and carcass weight.[17] NIR 2015 applied a further evolution in data sources and method, whereby abbatoir data was linked with ear tag identification to provide a more precise estimate of carcass weight for dairy cows that had been slaughtered after their first calving (see inventory practice: estimating animal weights using carcass weight data). The carcass ratio was also updated based on a research study (Minchin et al. 2009).

Milk yield data is official data from DEFRA statistics. Annual data on fat content derives from the Rural Payments Agency responsible for administering payments related to milk supply adjusted for butterfat content, which required wholesale purchasers of milk to record butterfat content.[18]

Earlier NIR submissions assumed digestibility (digestible energy as a percentage of GE) of 65% for dairy cows. NIR 2005 revised this estimate to 74.5%. The basis for this revision was an improved method for estimating cow energy requirements that was developed in 2004 to inform on-farm feed advice for dairy farmers (see Inventory Practice UK's country-specific method for estimating digestibility). In brief, the new method is an energy balance approach to estimate the metabolizable energy (ME) requirement for a dairy cow. First, typical concentrate use by farmers derived from a farm survey published in 2008 is combined with the digestibility (DE as a % of GE) of concentrate feed based on the typical mix of protein and energy feed ingredients. From this, the annual ME requirement that has to be met from forage is derived. The composition of forage (i.e. fresh grass, grass silage, maize silage) is then estimated on the basis of expert opinion, taking into account the proportion of time spent at grazing by dairy cows and the amount of maize grown in the UK, and digestibility values for these forage components are taken from national feed tables. The resulting estimated digestibility of 74.5% has since been used in each annual submission but is not updated annually.

Table 3: Data sources used for Tier 2 estimate of enteric fermentation emissions from dairy cows

Model parameter	**Data source in 2004**	**Data source in 2017**
Average live weight	Estimated assuming annual growth of 1% from 1990 onwards	Estimated from slaughter weight data provided by annual commissioned study

[17] https://www.gov.uk/government/collections/cattle-sheep-and-pig-slaughter

[18] http://webarchive.nationalarchives.gov.uk/20130904130448/http://rpa.defra.gov.uk/rpa/index.nsf/bea8273ecb2bce1080256c91005f564e/5a93aaf149a908f38025701b003cb8b4!OpenDocument

Calf birth weight (kg)	n.a.	n.a.
Coefficient for maintenance (Cfi)	IPCC default	
% of time spent on pasture	n.a.	Various studies and surveys collated for estimating AWMS in manure management
Coeff. for feeding situation (Ca)	IPCC default adjusted for proportion of time spent grazing/housed	IPCC default adjusted for proportion of time spent grazing/housed
Annual milk yield (kg)	DEFRA website	DEFRA website
Average fat content (% fat)	Rural Payments Agency	Rural Payments Agency
% pregnant in the year	n.a.	n.a.
Coefficient for pregnancy (Cpreg)	IPCC default	IPCC default
Digestibility	IPCC default	Expert judgment based on country-specific energy balance model
Gross energy (GE)	Calculated	Calculated
Methane conversion factor (Ym)	IPCC default (1996 GL)	IPCC default (2006 GL)
Emission factor	Calculated	Calculated

Note: n.a. indicates no information on data sources available

Beef cows: Initially, the UK lacked a time series of live weight data, so a constant live weight of 500 kg was assumed, and the resulting EF did not change from year to year. The calculated EF was close to the IPCC default, so initial submissions used the default value was used, but this was later replaced by the country-specific value. However, in NIR 2015, analysis of data for 2008-2012 from monthly abbatoir surveys on carcass weight data was combined with ear tag identification data to produce a more accurate estimate of carcass weight for beef cows that were slaughtered after their first calving (see inventory practice: estimating animal weights using carcass weigh data). A carcass ratio of 50% was applied to estimate live weight based on a scientific publication from a neighbouring country (Minchin et al 2009). This analysis of abbatoir data is repeated annually to produce a time series for beef cow live weight. Other parameters, such as milk yield, milk fat content and digestibility, are assumed to be constant, so the time series of the EF now varies in relation to the estimated live weight of beef cows.

Table 4: Data sources used for Tier 2 estimate of enteric fermentation emissions from beef cows

Model parameter	**Data source in 2004**	**Data source in 2017**
Average weight	Expert judgement	Estimated from slaughter weight data provided by annual commissioned study
Calf birth weight (kg)	n.a.	n.a.
Daily weight gain (kg/day)	Expert judgement	Expert judgement
Coefficient for maintenance (Cfi)	IPCC default	IPCC default
% of time spent on pasture	Expert judgement	Various studies and surveys collated for estimating AWMS in manure management
Coeff. for feeding situation (Ca)	IPCC default adjusted for proportion of time spent grazing/housed	IPCC default adjusted for proportion of time spent grazing/housed
Annual milk yield (kg)	n.a.	AFRC (1993)
Average fat content (% fat)	n.a.	n.a.
% pregnant in the year	n.a.	n.a.
Coefficient for pregnancy (Cpreg)	IPCC default	IPCC default
Digestibility	Expert judgement referring to national feed tables	Expert judgement referring to national feed tables
Gross energy (GE)	Calculated	Calculated

Methane conversion factor (Ym)	IPCC default (1996 GL)	IPCC default (2006 GL)
Emission factor	Calculated	Calculated

n.a. means description of data sources not available.

(2) Country-specific approach adopted in 2018

NIR 2018 adopts a country-specific methodology for enteric fermentation emission estimates from dairy and other cattle. In brief, the main features of the revised methodology are as follows:

Dairy cattle: Before 2018, the inventory represented only 1 dairy cow production system for the country, assuming a standard diet and average milk yield. The new methodology now represents 3 production systems based on breed, with breed- and region-specific data for milk yields and diet. This enables the inventory to capture changes such as increased use of forage maize. Research has established a close relationship between dry matter intake (DMI) and methane emissions, and DMI is now estimated on the basis of metabolizable energy which is determined using UK-specific energy balance equations as published in Feed into Milk (Thomas 2004):

$$CH4\_enteric\_dc = (15.8185 \times DMI) + 88.6002$$

Where:
CH_4_enteric_dc is the enteric methane emission per dairy cow, g d^{-1}
DMI is feed dry matter intake, kg d^{-1}.
Calculations are performed at a monthly resolution, with characterisation of production, management and feed by dairy cow category for each month.

Other cattle: Enteric methane emissions from other cattle, including dairy sector replacements and calves, and beef cattle, are estimated using the same approach as for dairy cows but with different relationships between enteric emission and dry matter intake. For non-lactating cattle:

$$CH4\_enteric\_oc = (17.5653 \times DMI) + 45.8688$$

where
CH4_enteric_oc is the enteric methane emission per animal, g d^{-1}.
For lactating suckler cows, the equation for dairy cows is used. For beef cattle, the inventory now represents 3 production systems ('continental', 'lowland native' and 'upland'), with 6 roles and 16 age bands in each. Monthly numbers of animals in each system are provided by the cattle tracing system.

The revised inventory shows 6%-7% lower total agricultural emissions than previously estimated, but the trend in emissions between 1990 and 2015 is very similar. One benefit of adopting more advanced approaches in the 2018 inventory is that the inventory is now capable of presenting the effects of adopting GHG mitigation practices, such as change in diet or breeds.

Manure management (Methane)

Manure management methane emissions from cattle are a key category (NIR 2017).

Approach used: IPCC approach (T2 for cattle and swine), T1 for other livestock.

Implementation of the approach: The source of activity data on livestock populations is as described above for enteric fermentation. The emission factors for manure management are calculated following IPCC Tier 2 methodology using default IPCC data for volatile solids (VS) and methane producing potential (Bo) parameters for each livestock type, except for dairy and beef cows, where a Tier 2 calculation following IPCC 2006 Equation 10.24 is used to determine VS. In calculating VS, the country-specific estimates for DE% used for enteric fermentation and the IPCC default ash content (i.e. 8%) are used. With the 2018 methodological revision, DMI is estimated using the UK-specific metabolizable energy equations, and VS is estimated on the basis of the GE of feed and feed energy content.

Initially, country-specific data on the proportion of manure managed in the different manure management systems derived from a number of sources, including commissioned research that used postal surveys of farmers (Smith et al. 2000, 2001a, 2001b), expert opinion, and other available data. Since 2012, the Farm Practices Survey (an annual representative survey of 2500 farms implemented by DEFRA) has included questions covering adoption of GHG mitigation practices, including manure and slurry management.[19] This data is now used in the estimation of proportion of manure managed in different management systems, and enables the inventory to reflect change in farming practices over time.

Uncertainty management

Until NIR 2015, the uncertainty associated with enteric fermentation and manure management was estimated using default estimates derived from the Watt Committee (i.e. ±20% for enteric fermentation and ±30.5% for methane emissions from manure management) (Williams 1993). NIR 2015 used results of a DEFRA-commissioned study that provided improved estimates of uncertainty associated with livestock methane and nitrous oxide emissions (Milne et al. 2014). Monte Carlo simulation was applied to propagate the uncertainty from input variables to the IPCC Tier 2 models for dairy and beef cattle through to the resulting estimated aggregate emission estimate. The disaggregated input data provided by each of the UK's devolved administrations was used, so the analysis provided geographically disaggregated insights into the main sources of uncertainty as well as identifying the contribution of GHG sources to uncertainty in the inventory. (see Inventory practice: Assessing uncertainty in the UK's livestock inventory).

Further resources:
UK national inventory reports, 2003, 2008, 2010, 2015, 2017, 2018

Milne, A.E., Glendining, M.J., Bellamy, P., Misselbrook, T., Gilhespy, S., Casado, M.R., Hulin, A., Van Oijen, M. and Whitmore, A.P., 2014. Analysis of uncertainties in the estimates of nitrous oxide and methane emissions in the UK's greenhouse gas inventory for agriculture. *Atmospheric environment*, *82*, pp.94-105.

Minchin, W., Buckley, F., Kenny, D.A., Keane, M.G., Shalloo, L. and O'Donovan, M., 2009. Prediction of cull cow carcass characteristics from live weight and body condition score measured pre slaughter. *Irish Journal of Agricultural and Food Research*, pp.75-86.

Misselbrook, T. (2018) New UK agriculture GHG and ammonia inventories. Presentation to National Farmer's Union.

Smith, K. A., Brewer, A. J., Dauven, A. and Wilson, D. W. (2000). A survey of the production and use of animal manures in England and Wales. I. Pig manure. Soil Use and Management 16, 124-132.

Smith, K. A., Brewer, A. J., Crabb, J. and Dauven, A. (2001a). A survey of the production and use of animal manures in England and Wales. II. Poultry manure. Soil Use and Management 17, 48-56.

Smith, K. A., Brewer, A. J., Crabb, J. and Dauven, A. (2001b). A survey of the production and use of animal manures in England and Wales. III. Cattle manures. Soil Use and Management 17, 77-87

Williams, A., 1993. Methane Emissions, Watt Committee Report Number 28, The Watt Committee on Energy, London

[19] https://www.gov.uk/government/statistics/farm-practices-survey-january-2012-greenhouse-gas-mitigation-measures

ANNEX 2: INVENTORY PRACTICE CASE STUDIES

Inventory practice: Livestock characterization and herd structure modelling in Georgia

Tags: livestock characterization | expert judgement | herd modelling | cattle | Asia

Country context: Georgia is a country in the Transcaucasus region that lies between Eastern Europe and Western Asia. The common native cattle breeds – Georgian Mountain and Red Mingrelian cattle – are late maturing breeds, characterized by small body size and low milk yields with high fat content. Intensive production systems are limited, and most cattle are raised in extensive grazing systems. During the period of the Soviet Union, more productive early maturing breeds were introduced. Georgia's GHG inventory began to use a Tier 2 approach for cattle in 2009. Prior to that, a Tier 1 approach was used by applying the IPCC default for the Asia region to late maturing breeds and the default values for Easter Europe to the early maturing breeds.

What data needs were addressed? Adopting a Tier 2 approach requires more detailed characterization of the cattle population, including sub-categories of cattle. However, national statistical data does not report any sub-categories of cattle.

Why was the data needed? Cattle account for about 90% of enteric fermentation emissions in Georgia. Enteric fermentation is a key source in the national GHG inventory. Therefore, following IPCC Guidance, a Tier 2 approach to estimation should be adopted, including enhanced characterization of cattle.

Methods used: Expert judgement for distribution of population among breeds; herd modelling for structure of the herd among age-sex groups.

How were livestock characterized? Georgia's GHG inventory categorizes cattle by breed as Georgian Mountain breed, Red Mingrelian or early maturing breed. This is because the characteristics of each breed differ (e.g. in terms of animal weight, milk production, fertility etc). Within each breed (or breed type), cattle are categorized into 17 types: 3 age groups of cow, 3 age groups of lactating cow, 3 age groups of bull (castrate), 3 age groups of bullocks, 3 age groups of heifers, and male and female calves <1 year old. Emission factors are estimated separately for each age-sex category for each breed.
The proportion of each breed in the whole cattle population was estimated using expert judgement. Then, within each breed, the annual population of each sub-category was estimated using a simple herd model based on the following assumptions:

1. Early maturing cattle have first calving at 3 years old, and are mature at 5 years old.
2. Late maturing cattle have first laving at 4 years old and are mature at 6 years old.
3. The average lifetime of an animal is 15 years.
4. A cow's gestation period is 9 months, with lactation for 12 months and a 2 month dry period.
5. The sex ratio of calf births is 50:50.
6. With a preference for veal, the calf slaughter ratio is higher and slaughter is assumed to take place in the middle of the year.

By applying these rules in a monthly time step model, the age and sex structure of the cattle population of each breed changes on a monthly basis and annual population estimates can be derived, considering the number of months each animal type is alive. Emission factors for each sub-category of animal are then estimated on the basis of age, sex and breed-specific characteristics (see examples in Tables 1-3), which are then applied to the modelled population to estimate total emissions.

TABLE 6.10: FEMALES LIVE-WEIGHT STANDARDS

Breed	live weight by moths, kg														
	Newborn	6	7	8	9	10	12	15	18	24	30	36	48	60	72
Georgian Mountain	13	55	60	70	80	85	100	115	130	135	157	169	180	200	210
Red Mingrelian	15	75	85	95	105	115	130	160	190	200	217	234	250	280	300
Early Maturing	32	152	168	187	203	220	250	297	345	397	420	443	487	520	520

TABLE 6.11: MALES LIVE-WEIGHT STANDARDS

Breed	live weight by moths, kg														
	Newborn	6	7	8	9	10	12	15	18	24	30	36	48	60	72
Georgian Mountain	13	60	65	75	85	95	110	140	160	190	220	255	290	320	320
Red Mingrelian	15	80	90	100	110	125	160	200	210	310	350	390	460	480	480
Early Maturing	32	170	195	225	240	263	310	385	458	543	613	693	773	820	820

TABLE 6.12: AVERAGE MILK PRODUCTION AND AVERAGE FAT CONTENT FOR COWS

Breed	Fat, %	Milk production, kg							
		Averaged in herd		1st lactation		2nd lactation		3rd and more lactation	
		Per year	Per day	Per year	Per day	Per year	Per day	Per year	Per day
Georgian Mountain	4.3	1,358	3.7	1,228	3.4	1,302	3.6	1,376	3.8
Red Mingrelian	4.3	1,460	4.0	1,047	2.9	1,269	3.5	1,491	4.1
Early Maturing	3.7	2,610	7.1	2,349	6.4	2,597	7.1	2,845	7.8

Source: Georgia NIR 2016

Further resources:
Georgia NIR 2016
IPCC 2006 Vol 4 Ch 10 Section 10.2 (livestock population and feed characterization).

Inventory practice: Dealing with missing data for livestock characterization in Austria

Tags: filling data gaps | livestock characterization | interpolation | extrapolation |cattle | Europe

Country context: Almost all enteric fermentation emissions in Austria are from cattle and Austria uses a Tier 2 appraoch for both dairy and non-daiary cattle. Since the mid-1990s, after Austria joined the EU, financial support for suckling cows increased (i.e. cattle are primarily raised for veal and beef with the milk of the cow only provided for the suckling calves), especially in mountain areas where the production system contributes to conservation of the traditional landscape. The area under organic production has grown, and now covers about 18% of total farm area in the country.

What data needs were addressed? Distribution of non-dairy cattle between organic and non-organic production systems.

Why was the data needed? Austria's country-specific enteric fermentation approach estimates GE from the typical dry matter intake (DMI) of cattle (see Austria country case study). Diets vary considerably between organic and non-organic production systems. Thus, it is necessary to estimate how many cattle are raised in organic and non-organic production systems. In Austria's initial inventory submissions, data on numbers of cattle on organic farms was available from the databases of INVEKOS, the control system used to manage EU subsidy payments. However, for some years the INVEKOS datatbase did not provide a breakdown of the cattle population by sub-category of cattle. Furthermore, the subsidy programmes covering cattle later ended and the inventory switched to a new data source on the organic cattle population from the Ministry of Agriculture's 'Green Report'. However, this change in data source resulted in missing data for some years not captured in either source. There were data gaps for the years 1990 – 1996 and for 2001 – 2003.

Methods used: trend extrapolation, interpolation of available data, expert opinion

How was the data gap addressed?
For all major animal categories the average share of organic farming in total agricultural land area in the 1997-2000 period was calculated from the INVEKOS data. This average share was then allocated to all animal sub-categories, assuming also that the cattle in organic and conventional farms have the same herd structures. This provided an estimate of the proportion of organic and non-organic cattle of different types. This structure was applied to the years 1990-1996 by extrapolating a trend in the animal population in organic and conventional farms based on the trend in existing data on the number of farms that apply organic farming practices. For the years 2001-2003, the data for 2000 was used, with no assumed trend over these years. After 2003, data from the Ministry of Agriculture's 'Green Report'.
The resulting estimate of livestock population in organic and conventional farming systems in different periods is shown in the table below. Because organic and non-organic cattle diets vary, the resulting activity data was then applied to different estimates of gross energy (GE) intake for each sub-type of cattle in each production system.

Estimated proportion of the population of cattle sub-types in organic production systems in Austria

IPCC Category	% organic	% organic	% organic
	1990	1997–2000	2009
CATTLE	1%	15%	18%
Dairy Cattle > 2 yr	1%	15%	17%
Suckling Cows > 2 yr	2%	25%	32%
Other Cattle > 2 yr	1.5%	20%	16%
Young Cattle < 1 yr	1%	13%	16%
Young Cattle 1–2 yr	1%	12%	16%

Source: Austria NIR 2011

Further resources:
Austria NIR 2011
IPCC 2006 Vol 1 Ch 2 (approaches to data collection)

Inventory practice: Use of existing data on cattle diets in Denmark

Tags: animal recording systems | feed tables | diet characterization | dairy cattle | Europe

What data needs were addressed? Definition of typical rations in the Danish dairy sector, which is used as input to calculation of gross energy per kilogram DM.

Why was the data needed? To estimate gross energy intake and establish the emission factor for dairy cattle, data on actual feeding practices (including nutrient content) is needed.

Methods used: data from dairy farm monitoring systems is used to create feed standards.

How was the data need addressed? In Denmark's inventory, calculation of gross energy per kilogram dry matter (DM) relies on the Danish Normative System. Normative standards are developed annually by the Danish Centre for Food and Agriculture (DCA), on the basis of data received from the central office for all Danish agricultural advisory services, SEGES.
The system is based on data on actual farming practices. In the dairy sector, 10% of the Danish dairy farmers are part of an intensive monitoring system, with the main purpose of establishing production benchmarks, optimizing productivity and for research. Four to eight times a year detailed data on livestock numbers, animal weight and rations are collected. Additional feed bought from outside the farm is included in the data collection. The data is used to establish normative standards. The normative standards establish the GE per kg DM in feed.

Further resources:
Denmark national inventory report 2018
Danish Centre for Food and Agriculture http://anis.au.dk/forskning/sektioner/husdyrernaering-og-fysiologi/normtal/.

Inventory practice: Estimating milk yields in Slovenia

Tags: filling data gaps | milk yield | extrapolation | dairy cattle | Europe

Country context: In the early 2000s, when Slovenia adopted a Tier 2 approach, cattle were responsible for about 90% of enteric fermentation emissions. The proportion due to dairy cattle has been declining over time, and in NIR 2017 less than 50% were from dairy cattle. However, average milk yield has been increasing from 2775 kg/head/year in 1990 to about 5590 kg/head/year in 2015.

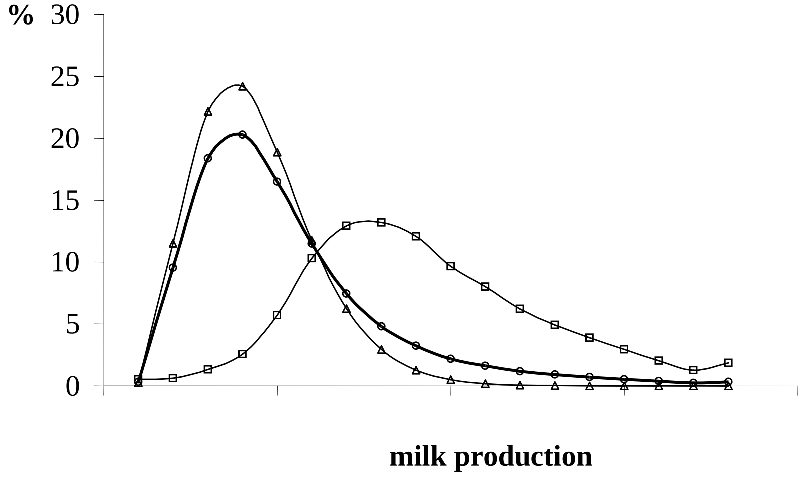
What data needs were addressed? Distribution of milk yield in the dairy cow population

Why was the data needed? Slovenia's national GHG inventory applies the IPCC model in a country-specific approach. In the initial Tier 2 submissions (e.g. NIR 2003), the IPCC model was used to estimate enteric fermentation methane emissions for 18 sub-categories of dairy cow defined by the level of milk yield (e.g. 1000 – 1500 L/ head/year; 1500 – 2000 L/ head/year…>9000 L/ head/year). A statistical relationship was then established between CH_4 emissions/head/year and milk yield kg/head/year. One option would be to apply the relationship to the average yield, but a better estimate would be obtained if the distribution of milk yields in the dairy cow population is known. Once the distribution of dairy cow milk yield in the population is known, then the inventory compiler can then estimate CH_4 emissions using this activity data. However, there was no official data that reports the distribution of milk yields for all Slovenian dairy cows. Milk yield monitoring data was available, however, from a sub-set of the dairy cow population.

Methods used: extrapolation

How was the data gap addressed? In 1999, the Cattle Breeding Service of Slovenia was monitoring monthly milk production by approximately 30% of the total dairy herd. These are referred to as 'controlled cows'. Inspection of this data revealed that the annual milk yield data has a gamma function distribution. The average milk yield of the controlled cows, total cow population and total milk production from statistical data (with adjustment for suckling by calves) was used to estimate the distribution of milk yield in the non-controlled cow population, assuming that it shared the same distribution as the data from the controlled cows. An iterative method was used to fit the gamma function to the non-controlled population such that the average milk yield estimated was equal to the average milk yield implied by the national statistical data. The controlled and (modelled) non-controlled populations were then combined (Figure 1). The resulting data on the numbers of cows producing at different levels of milk yield, was then applied to the estimated emission factor appropriate to each level of production to estimate total dairy cow enteric fermentation emissions.

Figure 1: Theoretical distribution of the controlled herd (□), adjusted non-controlled herd (Δ) and the entire, mathematically combined herd (○) of dairy cows



Source: Slovenia NIR (2004)

Further resources:
Slovenia NIR 2004, NIR 2017

Inventory practice: Estimating a time series for milk yields in Canada

Tags: filling data gaps | milk yield | extrapolation | dairy cattle | North America

Country context: Canada is a large and diverse country. Production practices vary across the country with differences in land prices, climate, forage availability and market access. Canada's inventory adopts a Tier 2 approach, but the inventory uses static values for the basic parameters describing dairy cattle production. For example, live weight, pregnancy rates and so on have the same value in each year. However, milk yield changes markedly over time.

What data needs were addressed? To develop a national time series for average milk yield per animal.

Why was the data needed? Milk productivity has increased in all Canadian provinces over time. CanWest DHI – a producer-owned milk recording organisation – collects a sample of milk production representing more than two thirds of the Canadian dairy cow population for the period of 1999–2015. These data give the best estimate of actual milk production per cow per province in Canada. However, from 1990 to 1998, this data set does not exist for the whole country. The only data that are available from 1990 to 1998 for all of Canada are data reported by Agriculture and Agri-Food Canada, which are collected on the most productive animals and during the first 305 days of lactation only.

Methods used: extrapolation

How was the data gap addressed? The time series of real milk production for the entire Canadian herd from 1990 to 1998 was calculated based on the average ratio between the data published by Agriculture and Agri-Food Canada and the milk recording data from 1999 to 2007. The trend of increased milk production is then reflected in the emission factor for dairy cows.

Further resources:
Canada NIR 2017

Inventory practice: Estimating cattle weights in the UK

Tags: filling data gaps | animal weight | surrogate data | cattle | Europe

Country context: In the early 2000s, cattle contributed about one third of UK total emissions of methane. In the early inventories, emission factors were separately estimated for four types of cattle (dairy breeding cows, beef cows, other cattle >1 year and other cattle<1 year. This was later increased to 8 sub-categories of cattle.

What data needs were addressed? Estimating average weights of cattle sub-categories

Why was the data needed? The UK's national GHG inventory implements the IPCC Tier 2 model for enteric fermentation and manure management, in which animal weight data is an important input. However, when the Tier 2 model was first used, the UK had no official data on cattle weights. In its initial Tier 2 inventories, animal weight in 1990 was estimated by expert judgement, and animal weight for subsequent years was estimated by assuming a 1% increase per year. In the mid-1990s, this method was replaced with data from expert judgement from staff of the responsibility government department, and by estimating average weight using the rolling average of previous estimates. In NIR 2007, for dairy cattle, these methods were replaced with the use of slaughter weight data, while constant weight estimated using expert judgement was assumed for beef cattle. Subsequently, in-depth analysis of slaughter weight data was used to provide better estimates of animal weight for both dairy and non-dairy cattle.

Methods used: estimation using slaughter weight data

How was the data gap addressed? The UK's livestock sector has suffered from several major disease outbreaks in the past 3 decades. One side-effect has been that more comprehensive registration and tracing of cattle. For example, the British Cattle Movement Service (BCMS) was set up in the wake of the BSE crisis in the late 1980s. The relevant legislation requires all bovines to have a unique ear tag and a cattle 'passport', which are handed to the abbatoir at slaughter, enabling full traceability of the source of all bovines slaughtered. EU legislation also required that a computerized system was put in place, and since the late 1990s, a Cattle Tracing System (CTS) records all births, movements and deaths. The CTS operates in England, Scotland and Wales, while a separate system operates in Northern Ireland. Abbatoirs are also legally obliged to identify each animal's provenance (through the ear tags and passport) and also collect data on carcass weight and record the category of animal (e.g. cow, heifer, steer, young or mature bull or calf).

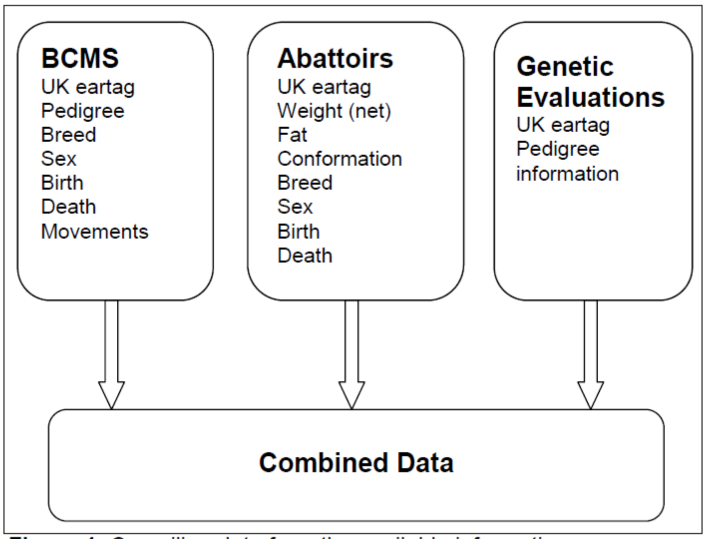


Figure 1 Compiling data from the available information sources

Source: Pritchard and Wall Selection opportunities from using abbatoir carcass data

Both CTS and abbatoir data record ear tag numbers, but the two datasets had never before been matched. Research by Tracey Pritchard and Eileen Wall at SRUC, primarily conducted for the purpose of producing estimated breeding values from carcass traits, matched the BCMS dataset with abbatoir data. For the purpose of estimating weights for the GHG inventory, ear tag numbers and associated birth date and sex records from the BCMS dataset were matched with ear tag numbers, sex record and net weight data from 6 abbatoirs. In 2014, 3.9 million carcass records from 2001-2014 were obtained from the abbatoirs, representing about 30% of the national slaughter population. For 4 abbatoirs, almost all ear tag identifiers could be matched with identifiers in the BCMS dataset. For two abbatoirs, however, because a portion of intake came from Ireland or Northern Ireland, the datasets could not be matched. The data also had to be cleaned to remove very low net carcass weight estimates that probably represented erroneous data entry. Thus, the average net carcass weight for each category of cattle (defined by age at slaughter and sex) could be calculated. A comparison of the national herd population data with the structure of the abbatoir sample data showed that the composition of the abbatoir sample closely resembled that of the national herd. Thus, although the data represent 30% or less of the national herd slaughtered every year, it can be considered representative.

The net cacrass weight data supplied by the researchers to DEFRA for GHG inventory compilation is then converted to a live weight estimate assuming a killing out percentage of 50%, which was applied to all breeds. This estimate derived from research conducted in Ireland – which has similar breeds and production system to much of the UK – that was published in a scientific journal (Minchin et al 2009).

The original research that produced these data continues with funding from the Agriculture and Horticulture Development Board – a statutory levy board independent of industry and government – to further research on the genetics of lifetime performance. Several abbatoirs now send slaughter records on a monthly basis by automated data transfer. The BCMS and the abbatoirs have signed data sharing agreements with SRUC, as the data is commercially sensitive. The use of the data for making inputs into the national GHG inventory is the only agreed use outside of the primary purpose of the genetics research.

Further resources:

Moore, K. et al. (n.d.) Using abattoir generated data and BCMS records for carcase trait evaluations. Final project report. Available at http://beefandlamb.ahdb.org.uk/research/genetic-selection/genetic-selection-beef/carcass-trait-evaluations/

Wall, E., Coffey, M. and Pritchard, T., Selection opportunities from using abbatoir carcass data. In *Proc. Assoc. Advmt. Anim. Breed. Genet* (Vol. 20, pp. 253-256). Available at http://www.aaabg.org/aaabghome/AAABG20papers/wall20253.pdf

Minchin, W., Buckley, F., Kenny, D.A., Keane, M.G., Shalloo, L. and O'Donovan, M., 2009. Prediction of cull cow carcass characteristics from live weight and body condition score measured pre slaughter. *Irish Journal of Agricultural and Food Research*, pp.75-86.

IPCC 2006 Vol 4 Ch 10 p.10.12

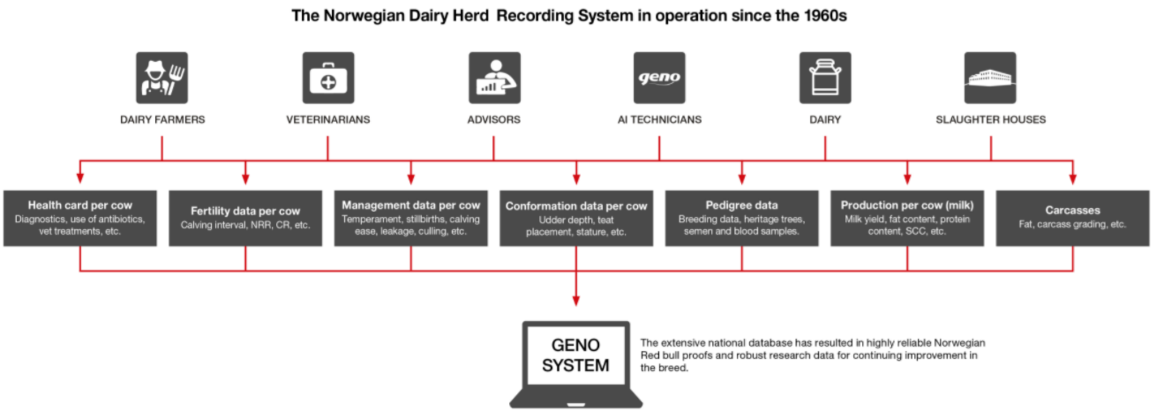
Inventory practice: The role of cow recording systems in Norway's Tier 2 approach

Tags: livestock information resources | cow registers | dairy cattle | Europe

Country context: Until 2006, Norway used a Tier 1 approach for estimating enteric fermentation in cattle. Enteric fermentation was identified as a key source due to uncertainty in both the level and trend in emissions. NIR 2006 first adopted a Tier 2 approach. Norway's Tier 2 approach is a country-specific method in line with IPCC guidance. It was designed to take advantage of information resources available in the livestock sector.

Livestock information resources used: Subsidy payment database; cow recording system; research

How did livestock sector information resources help shape the Tier 2 approach? Since the 1960s, the Norweigan Dairy Herd Recording System (NDHRS) has been operated by TINE SA, a farmer-owned dairy cooperative. The NDHRS covers almost all dairy cows in the country. The system collects a range of information on dairy cows that is used for various purposes, including animal health montoring and genetic evaluation. Some of the information is also used in the national GHG inventory.



Source: https://www.norwegianred.com/Start/Norwegian-Red/about-norwegian-red/Norwegian-red-breeding-program/

Data on the population of 8 sub-categories of cattle in the GHG inventory derive from the official registry of production subsidies, which covers more than 90% of animals. Data on parameters used to estimate emissions per head per year for each sub-category derive from the NDHRS. The NDHRS includes records of physiological status (dry, lactating or pregnant), annual milk production, feeding, live weight, slaughter age, slaughter weight and average daily weight gain (ADG) for growing cattle, which are utilized in the calculations for growing cattle.

For dairy cattle, Norway's Tier 2 approach takes account of both milk production levels and diet composition. In particular, Norway's approach uses equations to estimate gross energy (GE) and methane conversion rate (Ym) on the basis of milk yield and feed characteristics, both of which are recorded in the NDHRS. Although the specific equations used to estimate GE and Ym have developed over time, the basic input data continue to be supplied by the NDHRS. The data available in the recording system have thus played a key role in shaping Norway's choice of estimation method.

When Norway first developed its Tier 2 approach, more than a million observations from the NDHRS were used to develop standard lactation curves in 500 kg intervals from 4500 to 9500 kg (over a 305 day period). Standard feed rations for each 500 kg interval were then calculated using different combinations of forage quality and different levels of concentrate to produce low, medium and high energy content rations at each production level. These standard rations thus covered the normal range of forage qualities as indicated by the feed information in the NDHRS. Initially, feed energy values were estimated using the Dutch net energy lactation system that had been the official energy system in Norway since the early 1990s. Later, this was replaced by energy values estimated using the Nordic feed evaluation system (NorFor), but the overall approach remained the same.

For estimation of methane emissions, Norway's initial Tier 2 approach used two equations based on overseas research that had been published in the literature: an equation by Mills et al (2003) was used to predict daily CH_4 production on the basis of feed intake and dietary ADF and startch content; and an equation described by Kirchgessner et al (1995) was used to predict CH_4 per day on the basis of crude protein and fat and NFE contents of the diets. The estimated CH_4 emissions were taken as the average of the values predicted by these two equations.

The 305 day lactation curves and the standard feed rations modelled were then used to estimate average daily GE intake across each stage of lactation, at different milk yield levels and with different concentrate proportion in the diet. The reason this was done is because milk yield and concentrate proportion are available in the NDHRS. The resulting equation ($GE = 150.8 + 0.0205 \cdot Milk_{305} + 0.3651 \cdot Concentrate\_prop$) enables GE to be estimated on the basis of milk yield and concentrate proportion in the diet, both of which are available from the NDHRS. Another equation was also developed for Ym ($Ym = 10.0 – 0.0002807 \cdot Milk_{305} – 0.02304 \cdot Concentrate\_prop$) that uses these input data.

These prediction methods were subsequently updated, but the methodological approach remains the same. On the basis of published research using the NorFor model (Storlein et al 2014), a new equation predicting daily methane emissions on the basis of DMI and fatty acid content was used (CH_4 (MJ/d) = 6.80 + 1.09 × DMI − 0.15 × FA), along with revised equations for GE ($GE =137.9 + 0.0249 \times Milk_{305} + 0.2806 \times Concentrate\_proportion$) and Ym ($Ym = 7.15 – 0.00004 \times Milk_{305} – 0.00988 \times Concentrate\_proportion$). The estimated Ym values using the revised method were closer to those suggested in the IPCC 2006 Guidelines than the estimated values using the previous equations.

Thus, as Norway gradually improved the specific methods used to estimate dairy cattle emissions, the overall methodological approach remained the same. The availability of data from the NDHRS to populate the country-specific models was one key factor determining the choice of country-specific approach.

Further resources:

Norway Statistics Office, 2011. National Inventory Report, Appendix H: Enteric methane emissions from cattle and sheep population in Norway. Method description. https://www.ssb.no/en/natur-og-miljo/artikler-og-publikasjoner/_attachment/279491?_ts=1576a6ddf40

Storlein, T.M and Harstad, O.M. Enteric methane emissions from the cattle population in Norway. Annex IX in Norway NIR 2017.

Storlien, T.M., Volden, H., Almøy, T., Beauchemin, K.A., McAllister, T.A. and Harstad, O.M., 2014. Prediction of enteric methane production from dairy cows. *Acta Agriculturae Scandinavica, Section A—Animal Science*, *64*(2), pp.98-109.

Inventory practice: Integrated data management in Denmark

Tags: inventory database | Europe

What data needs were addressed? Structured data management for accurate and consistent estimates of emissions.

Why was the data needed? To determine GHG emissions from enteric fermentation and manure management and ensure that data is managed for consistency, completeness and timely submission of the inventory.

Methods used: Design of an integrated relational database system.

How was the data need addressed? To enable structured input data management as well as establish linkages between some of the input data collected, the 'Integrated Database model for Agricultural Emissions' was developed by the Department of Environmental Science of Aarhus University. In one database, 'IDA-backend', input data is stored and updated annually. The database is linked to a number of equations in the actual IDA database, where the calculations of emissions are implemented. Only the input data is updated annually, the equations and calculations are then automatically updated in the system.

Differentiated according to livestock type, weight class and age, 39 different livestock categories are represented within IDA. Using housing and manure type, these categories are further subdivided, resulting in 269 different combinations of livestock sub-categories and housing types. For each of these combinations, information on feed intake, digestibility, excretion and grazing days is included, and emissions are calculated.

The system enables the consistent estimate of GHG emissions from livestock. It is used to cover emissions of air pollutants and greenhouse gases. A direct link between input data is used to estimate methane emissions from enteric fermentation and manure management. Furthermore, a direct coherence exists between input data used to estimate methane, ammonia (NH_3) and N_2O emissions.

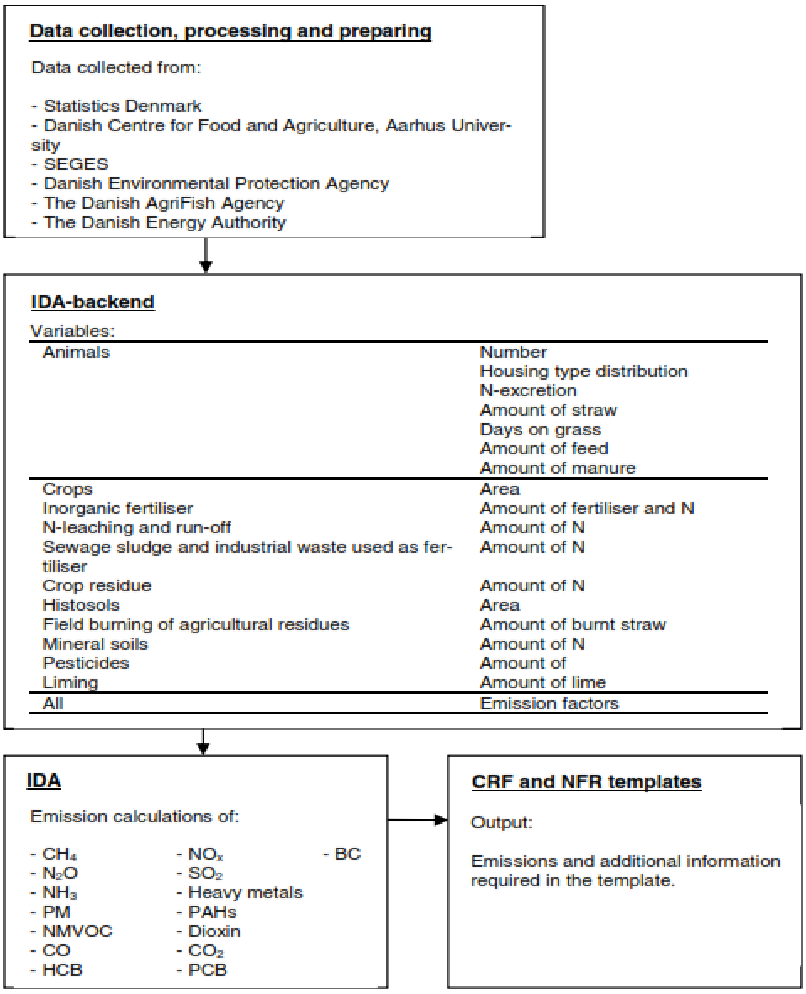


Figure 5.2 IDA - Integrated Database model for Agricultural emissions.

Further resources:

Danish emission inventories for agriculture: inventories 1985 – 2015 http://dce2.au.dk/pub/SR250.pdf

Inventory practice: Estimating digestibility using a country-specific approach in the UK

Tags: filling data gaps | feed digestibility | national energy balance model | dairy cattle | Europe

Country context: In the early 2000s, cattle contributed about one third of UK total emissions of methane. In the early inventories, emission factors were separately estimated for four types of cattle (dairy breeding cows, beef cows, other cattle >1 year and other cattle<1 year. This was later increased to 8 sub-categories of cattle. Dairy cattle are a major source of emissions.

What data needs were addressed? Improved estimates of feed digestibility were needed.

Why was the data needed? The UK's national GHG inventory implements the IPCC Tier 2 model for enteric fermentation and manure management, in which feed digestibility is an important input. When the Tier 2 model was first used, the UK used expert judgement and IPCC default values. Subsequently, improvements in knowledge in the dairy sector indicated that these prior estimates required revision.

Methods used: A national energy balance model developed for farm feed and nutrition planning was used

How was the data gap addressed? For dairy cows, a country-specific approach to estimating digestibility of feed (DE%) has been developed. This country-specific approach is based on the models that underlie extension advice to farmers using the Feed into Milk (FiM) model. The reason for using this country-specific approach is that feed concentrate provides an important part of the dairy cow diet. The Feed into Milk model was developed to provide a better estimate of voluntary feed intake in order to better meet the energy and protein requirements of high yielding dairy cows.

The FiM model was developed in the early 2000's to replace earlier (1993) feed nutrition tables as the basis for software programmes for use by farmers in feed and nutrition planning. The model has modules for prediction of feed intake, energy requirements and supply, and protein requirements and supply.

Feed intake equations were specifically developed using data from cows fed on different diets in experiments at several UK research institutes and were validated against independent datasets. Thus, the equations can be used to predict feed intake across a range of forage and concentrate diets. The feed intake prediction equation uses information on concentrate intake and its protein content, body condition, live weight, milk energy output, week of lactation and starch content of forage. In particular, the feed intake equation developed predicts intake of grass silage-based diets more accurately than previous equations used to inform dairy nutrition advice.

Extension advice for dairy production in the UK has been based on the UK metabolisable energy (ME) feeding system, first proposed for use in the UK by the agricultural Research Council in 1965 (with revisions in 1980, 1990 and 1993). One strength of the system is that its mathematical structure enables it to easily be used in conjunction with feed value tables. The revision in FiM was needed to account for the higher genetic merit of modern cows, changes in representative diets and observed changes in ME requirements for maintenance. A new empirical model was made relating milk energy output (i.e. product of milk yield and gross energycconcentration of the milk) and measured ME input, with full measurement of losses in faeces, urine, methane and heat. The resulting equations predict ME requirements for maintenance and also the efficiency of ME use for lactation that varies with milk energy for lactation. On this basis, the total ME requirements for body weight gain, pregnancy, maintenance and milk production and activity can be estimated.

Table A 3.3.6 Calculation of digestibility (dairy cows)[a]

1	Total annual energy requirement for 'average' UK dairy cow		
	Assumed parameters - 7,000 litres, 600 kg live weight		
	ME lactation (MJ)	36050	- Derived from 'Feed into Milk' (2004) - See also Alderman and Cottrill (1993)
	ME pregnancy (MJ)	2400	
	ME maintenance (MJ)	28760	
	Annual ME requirement (MJ)	67210	Sum of ME lactation+ ME pregnancy+ ME maintenance
	Annual DE requirement (MJ)	82975	Assuming ME = 0.81 x DE (factor from Alderman, 1982)
2	Energy supplied from concentrate feed		
	Average annual milk yield (litres)	7000	
	Average concentrate use (kg FW/litre)	0.28	From Nix, 2009
	Annual concentrate use (kg FW)	1960	
	Annual concentrate use (kg DM)	1705.2	Assumes DM content of concentrate of 87% (MAFF, 1990)
	GE supplied by concentrates (MJ)	30491	Calculated from values given in MAFF, 1990 (see Table A 3.3.5)
	DE supplied by concentrates (MJ)	24961	Calculated from values given in MAFF, 1990 (see Table A 3.3.5)
3	Remaining energy supplied from forage		
	DE to be supplied by forage (MJ)	58015	
	Forage DM required (Kg)	4301	Proportion concentrate in diet: 28%[a]
	GE supplied by forage (MJ)	80851	Proportion forage in diet: 72%[a]
4	Diet digestibility		
	Total GE intake (MJ)	111341	
	Total DE intake (MJ)	82975	
	Digestibility (ME/GE), %	74.52341	

[a]See explanation of calculations in main chapter section 6.2.2.1
Data from: Feed into Milk (2004); Alderman and Cottrill (1993); Alderman (1982); Nix 2009: Nix, J. (2009); MAFF (1990)

In the national GHG inventory, the FiM model is used to first estimate metabolisable energy for a typical level of milk production, in this case 7000 liters. At this level of production, the farm management guide suggests average concentrate use of 0.28 kg per liter (Nix 2009). The digestibility (DE as % of GE) value for concentrate feed (c. 82%) is estimated on the basis of a typical mix of protein and energy feed ingredients in concentrate. Using this value for ME supplied by concentrate, the annual ME requirement that has to be met from forage can then be derived. This is useful because the UK does not have detailed survey data on the amount of forage consumed by dairy cows. Assuming on the basis of expert opinion taking into account the proportion of time spent grazing by dairy cows that forage consists of 40% fresh grass, 50% grass silage and 10% maize silage, the relative proportions of concentrate to forage DM intake per year are estimated as 29% concentrate and 71%

forage. The digestibility values for forage components are taken from the official feed nutrient value tables (MAFF 1990).

The use of FiM is specifically for dairy cows. For beef cattle, digestibility values are based on expert opinion.

Further resources:

UK NIR 2017

Thomas, C. (2004) Feed into Milk; An advisory manual. Available at: https://bsas.org.uk/sites/default/files/files/FiM-Book.pdf

Inventory practice: The use of the Karoline model to predict methane yield

Tags: methane conversion factor | modelling | dairy cattle | Europe

What data needs were addressed? Prediction of methane yield.

Why was the data needed? To establish a methane conversion factor.

Methods used: Mechanistic model.

How was the data need addressed? The Karoline model is intended to be used by advisory services in Nordic countries including Denmark. The model simulates animal performance (i.e. milk yields) of a given feed in a given situation. The model is a dynamic and mechanistic simulation model for lactating dairy cows, and consists of two 'sub-models': one digestion, and one metabolism model. Model inputs include liveweight, week of lactation, rate of dry matter (DM) intake and DM composition. Numerous feed parameters are included as well, including crude protein (CP), crude fat, potentially degradable neutral detergent fibre (NDF), totally indigestible NDF, starch (St), fermentation products and a rest fraction (RF). Model outputs include parameters measuring digestion and nutrient use efficiency (e.g. use of metabolizable energy for lactation), production parameters (milk yield, milk composition, live weight gain), and protein and energy values of the feed ration.

The model can also be applied to quantitative prediction of methane emissions from dairy cows under varying conditions, depending on (i) level feed feeding, (ii) proportion of concentrates in the ration, (iii) digestibility of roughages and (iv) fat, sugar and starch content in the feed. Results from the model are in accordance with experimental data (Ramin and Huhtanen 2015), hence the model is considered a reliable model for predicting methane emissions from mature dairy cows.

Further resources:

Olesen, J.E., Jørgensen H., Danfær A., Gyldenkærne S., Mikkelsen M.H., Asman W.A.H. and S.O. Petersen (2005). Evaluering af mulige tiltag til reduktion af landbrugets metanemissioner. Arbejdsrapport fra Miljøstyrelsen Nr. 11 2005.

Sveinbjrnsson J., Huhtanen P. and P. Udn (2006). The Nordic Dairy Cow Model Karoline - Development of Volatile Fatty Acid Sub-Model. Nutrient digestion and utilization in farm animals: modelling approaches, Page: 1-14.

Ramin, M. and Huhtanen, P., 2015. Nordic dairy cow model Karoline in predicting methane emissions: 2. Model evaluation. *Livestock Science*, *178*, pp.81-93.

Inventory practice: Modelling rumen processes in The Netherlands

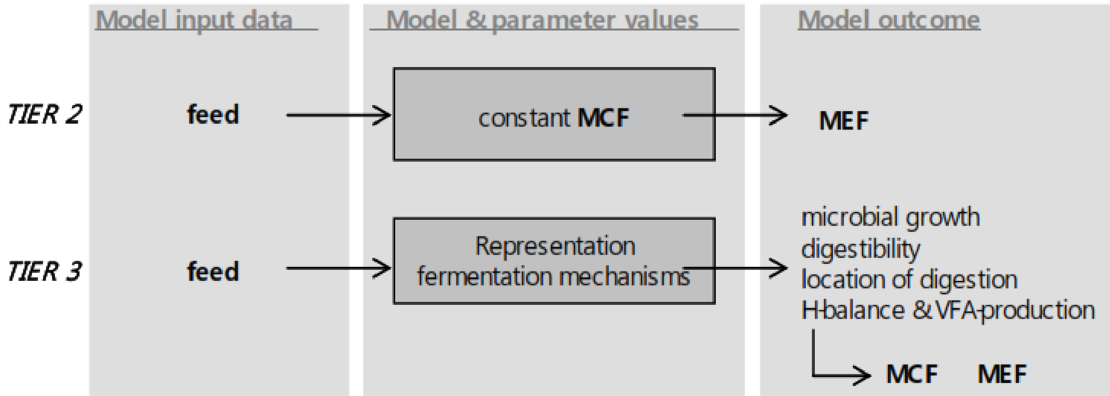
Tags: methane conversion factor | modelling | dairy cattle | Europe

What data needs were addressed? More accurate estimation of methane emissions from dairy cattle.

Why was the data needed? To account for high nutritional quality of dairy rations in The Netherlands.

Methods used: Prediction of the CH_4 conversion factor from feed intake and dietary characteristics, using a dynamic model.

How was the data need addressed? Until 2005, The Netherlands used a Tier 2 approach to estimate methane emissions from mature dairy cattle. However with high quality (and thus digestibility) of dairy rations, it was suspected the IPCC default value was too high. Furthermore the constant default factor did not reflect variation in the level of feed intake, digestibility, composition and quality of the ration. Thus, the methodology was improved by adopting a country-specific Tier 3 approach.



Source: Bannink 2011

The approach is built on a model, originally developed for modelling rumen processes in dairy cattle. The model predicts methane production as a result of the microbial fermentation process in the gastrointestinal tract of dairy cattle. The model appeared suitable for modelling methane emissions as well by taking more detailed ration composition and quality into account.
Instead of using a constant country-specific emission factor, the model predics the methane conversion factor based on feed intake, ration composition, nutrient content and quality. The model represents the mechanisms for microbial degradation of feed particles. Using volatile fatty acids as end-product of rumen fermentation, methane emissions can be estimated.
The emission factor, gross energy and methane conversion factor are calculated annually.

Further resources:

The Netherlands' NIR 2018

Bannink, A., van Schijndel, M.W. and J. Dijkstra 2011. A Model of Enteric Fermentation in Dairy Cows to Estimate Methane Emission for the Dutch National Inventory Report Using the IPCC Tier 3 Approach. Animal Feed Science and Technology, 166-167, 603-618. http://dx.doi.org/10.1016/j.anifeedsci.2011.04.043

Vonk, J., S.M. van der Sluis, A. Bannink, C. van Bruggen, C.M. Groenestein, J.F.M. Huijsmans, J.W.H. van der Kolk, L.A. Lagerwerf, H.H. Luesink, S.V. Oude Voshaar & G.L. Velthof (2018). Methodology for estimating emissions from agriculture in the Netherlands – update 2018. Calculations of CH4, NH3, N2O, NOx, PM10, PM2.5 and CO2 with the National Emission Model for Agriculture (NEMA). Wageningen, The Statutory Research Tasks Unit for Nature and the Environment (WOT Natuur & Milieu). WOt-technical report xxx. xxx p; 54 Tab.; 2 Fig.; 102 Ref.; 12 Annexes.

Inventory practice: Aligning national GHG inventories, NDCs and NAMAs in Kenya

Tags: mitigation policy | dairy cattle | Africa

What needs are being addressed?
Climate policy is a rapidly developing area. Elaboration of national policies, international commitments and sub-national actions often takes place in parallel. Kenya's experience shows the important role that improvements in the national GHG inventory can play in aligning the measurement, reporting and verification (MRV) of initiatives at national and sub-national level, as well as alignment with accounting for the NDC at international level.

Linking NAMAs and NDCs: Kenya's National Climate Change Action Plan (NCCAP) is the guiding document for climate-related policies and measures in Kenya. In order to identify opportunities and priorities for GHG mitigation, the NCCAP described a 'reference case' or business-as-usual scenario for national GHG emissions to 2030, and highlighted opportunities for reducing national GHG emissions below that scenario. Analysis of mitigation potentials then informed Kenya's INDC target for mitigation. In some sectors, where prior bottom-up analysis had been conducted, the mitigation opportunities were closely linked to specific policies and measures. For the agriculture sector, a target or reducing emissions by 30% was set, and promising options were identified, but specific measures to achieve that target were not determined.

For livestock emissions, analysis in the NCCAP assumed that the trend in emissions would be a continuation of historical trends in livestock population and a constant Tier 1 emission factor. Bottom-up analysis of mitigation potential in the livestock sector was not available when the NCCAP was being drafted, so the priorities set out in the Action Plan were not informed by specific analysis of livestock sub-sectors. And in any case, quantification of emission reductions would not have been possible using a fixed Tier 1 emission factor.

Kenya's dairy NAMA began to be developed after the release of the Action Plan. When developing BAU scenarios for the dairy sector, the NACCP was consulted, but because of the limitations of the methods used in the analysis for the NACCP, new scenarios were developed for the dairy NAMA. These scenarios were developed taking Kenya's Dairy Master Plan (DMP) as a guide, in which per capita milk demand is forecast to double by 2030. A BAU scenario (i.e. the DMP's target is met with no change in emission intensity), and several mitigation scenarios (i.e. the DMP's target is met with different trends in emission intensity over time) were produced using a Tier 2 model (GLEAM) that was able to relate scenarios for dairy cattle populations and milk yield to changes in emission factors and emission intensity. The resulting scenarios are closely related to dairy sector policy scenarios, but not to analysis underlying national climate policies. Better alignment of mitigation ambition in the livestock sector with analysis underling the NDC will require that the NDC is informed by analysis using a Tier 2 approach to quantification of livestock emissions.

Linking NAMAs and national GHG inventories: The MRV methodology proposed for Kenya's dairy NAMA involves establishing a baseline through regional surveys of smallholder dairy farms to collect data needed to estimate emission intensity using a Tier 2 approach in each region. Emission reductions due to changes in emission intensity and yield will be calculated in comparison to this baseline. On this basis, the resulting emission reductions can be reported to the agencies that fund implementation of the NAMA. They can also be reported in the mitigation section of the Biennial Update Report, along with a description of the methodologies and assumptions used in estimating emission reductions. However, because the emission reductions will be achieved through improvements in dairy cow productivity, the resulting changes in emissions per animal would not be reflected in the national GHG inventory. Kenyan stakeholders have thus become aware of the relevance of adopting a Tier 2 approach for dairy cattle in the national GHG inventory.

How are the needs being addressed? In 2018, a national workshop was convened by the State Department of Livestock to discuss with stakeholders their support for beginning the process of adopting a Tier 2 approach for dairy cattle emissions. Stakeholders from livestock, climate, and statistics departments, along with national and international researchers shared information on related initiatives, came to a consensus on the need to adopt a Tier 2 approach, and made suggestions for how this work can be coordinated and the support that would be needed.

Further resources:
Kenya NCCAP http://www.kccap.info/
Kenya INDC
http://www4.unfccc.int/ndcregistry/PublishedDocuments/Kenya%20First/Kenya_NDC_20150723.pdf
Kenya Dairy NAMA: http://www.kilimo.go.ke/index.php/2018/03/19/low-emission-and-climate-resilient-dairy-development-in-kenya-dairy-nama/
FAO & New Zealand Agricultural Greenhouse Gas Research Centre. 2017. Options for low emission development in the Kenya dairy sector - reducing enteric methane for food security and livelihoods. Rome. 43 pp. http://www.fao.org/3/a-i7669e.pdf

Inventory practice: Operational planning for a Tier 2 inventory in Kenya

Tags: planning | dairy cattle | Africa

What needs were addressed?
Kenya has been developing a nationally appropriate mitigation action (NAMA) in the dairy sector. Quantification of the resulting emission reductions will use a Tier 2 approach. However, the national inventory and the projected scenarios underlying Kenya's national climate change action plan and NDC use a Tier 1 approach, which cannot reflect the effects of productivity increases due to NAMA implementation. Therefore, the State Department of Livestock decided to initiate a process of consultation and planning for development of a Tier 2 approach for the national GHG inventory.

How were the needs addressed? In early 2018, the State Department of Livestock (SDL), with support from FAO and GRA, convened a consultation meeting. Participants from the Ministry of Environment, national statistical agencies and dairy sector stakeholders agreed on the necessity for adopting a Tier 2 approach for dairy cattle in the national inventory. In June 2018, a further workshop was convened, attended by representatives of the Climate Change Directorate (CCD) which is responsible for the inventory, other government agencies as well as dairy sector technical specialists. The workshop provided training in the technical requirements for a Tier 2 inventory, outlined an overall structure for the inventory, and assessed the availability of the data required. One key outcome of the workshop was an outline action plan for delivering a draft inventory by December 2018, for validation and inclusion in the next UNFCCC submission by February 2019. Table 1 presents a summary of the action plan discussed. Specific dates, resources required and individuals involved have yet to be confirmed.

Table 1: Outline action plan for developing a Tier 2 inventory for dairy in Kenya

	What to do	Who's responsible / involved	Notes
1	Form initial 'core team'	SDL + others tbc	
2	Appoint 'project manager'	SDL + others tbc	Manager is needed to make sure work proceeds continually
3	Make work plan	Core team	
4	Agree Structure of inventory	Core team	
5	Define data needs	Core team	Incl. data needs and formats required
6	Develop spreadsheet/software	Core team	
7	Consultation on members of inventory team	SDL lead consultation	
8	Training on IPCC Tier 2 model & inventory compilation for inventory team		
9	Identify data sources / providers	Inventory team	
10	Collate data	Inventory team	Incl. literature review

11	Analyse data	Inventory team	Statistical support needed?
12	Agree activity data & MCF values to use	Inventory team	Engage with ag statistics committees to ensure consistency
13	Document all data sources and values chosen	Inventory team	
14	Input data into software	Inventory team	
15	Analyze/assess initial results	Inventory team	
16	Assess gaps/limitations, propose priority improvements	Inventory team	
17	QA/QC – checking for mistakes etc	Inventory team	
18	QC by experts from the sector	SDL lead	
19	QA to check against other countries' figures	CCD experts	
20	Stakeholder review of initial results	tbc	
21	Revise draft	Inventory team	
22	Submit to CCD	SDL	
23	External review	CCD	

Further resources:

Kenya NCCAP http://www.kccap.info/

Kenya INDC http://www4.unfccc.int/ndcregistry/PublishedDocuments/Kenya%20First/Kenya_NDC_20150723.pdf

Kenya Dairy NAMA: http://www.kilimo.go.ke/index.php/2018/03/19/low-emission-and-climate-resilient-dairy-development-in-kenya-dairy-nama/

FAO & New Zealand Agricultural Greenhouse Gas Research Centre. 2017. Options for low emission development in the Kenya dairy sector - reducing enteric methane for food security and livelihoods. Rome. 43 pp. http://www.fao.org/3/a-i7669e.pdf

Inventory practice: Institutional arrangements for compilation of Austria's livestock emissions inventory

Tags: Institutional arrangements | planning | Europe

Country context: Austria's inventory approach for Tier 2 estimation of cattle emissions uses prior research to establish relationships between gross energy intake and animal performance parameters. For dairy cattle, a relationship between milk yield and gross energy intake has been established, and for other cattle, gross energy intake of different sub-categories has been established based on animal performance and typical feed characteristics. Using this prior research, compilation of the annual inventory only requires data on animal population numbers in each category and milk yield. See Country Inventory Case Study: Austria.

Institutional arrangements:
The Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW) is responsible for Austria's reporting obligations. It has established an Inspection Body for Emission Inventories (IBE) that compiles the annual GHG inventory. The personnel of the IBE are made up of staff from various units of the ministry. For each inventory sector, two experts form a sector team. These experts collect activity data, emission factors and all relevant information needed for finally estimating emissions. The sector experts are also responsible for the choice of methods, data processing and archiving and for contracting studies, if needed. As part of the quality management system the Head of the IBE approves methodological choices. Before methodologies are applied the methodology is defined as a SOP (standard operating procedure) together with a template for calculating emissions, where needed. The SOP is checked for applicability and completeness of information needed and finally approved by the head of the inspection body. New and changed calculation files are validated before use. Once data has been collected, it is entered together with emission estimates into a centralized database, where data sources are well documented for future reconstruction of the inventory. The sector experts are also responsible for QA/QC activities.

For livestock emissions, data comes from prior national studies and annual data on livestock population and milk yields reported by Statistics Austria. Provision of this data is part of the legal mandate of Statistics Austria.

Inventory compilation process:
Austria's inventory is compiled in accordance with an annual plan (Table X). Annual planning begins with sectoral improvement planning, in which the sector team discusses all issues related to the sector with the head of IBE, assesses all issues according to their urgency and resource needs, and finally agrees on measures and activities to implement. Following this, a management review meeting is held at which the previous year's activities and performance are reviewed, including quality management activities, and measures are set for improving the management system and its processes, including plans for internal audits, QA and verification activities as well as training and resource plans.

Table 1: Overview of inventory related tasks

Task	Description	Deadline
Management Review	Preparation of a report including evaluation of the fulfilment of the previous improvement plan anda plan for QMS and inventory improvement, i.a. based on audit and review findings.	Summer
Kick-Off	Meeting of inventory team (sector experts, deputies, project-/quality- and data managers of the inventory); definition of a working plan	End of Summer
Activity data collection	Collection of activity data, including contracting out studies.	November 15
Inventory preparation	Estimation of emissions for all sources, including collection of background data.	December 15
Compilation of national inventory	Updating the data base and conversion to the CRF reporter	December 23
Quality checks	Tier 1 and Tier 2 QA/QC activities	December
Compilation of report (Short-NIR)	Compilation of a inventory report 'Short NIR' and submission to the EC (MMR Monitoring Mechanism Regulation No 525/2013)	January 15
Preparation of NIR	Compilation of the National Inventory Report	January–March
EU Submission NIR	Submission ot the National Inventory Report to the EC (MMR)	March 15
UNFCCC Submission NIR	Submission ot the National Inventory Report to the UNFCCC	April 15

Further references:

Austria (2017) National Inventory Report.

Inventory practice: Institutional arrangements for data supply in Denmark's inventory

Tags: Institutional arrangements | Europe

What data needs were addressed? Institutional arrangements for data collection, exchange and collaboration.

Why was the data needed? Compilation of input data for the annual inventory.

Methods used: Close cooperation between statistics, research institutes and advisory services.

How was the data need addressed? Both the Danish Centre for Environment and Energy (DCE) and Aarhus University have established data agreements (MOUs) with institutes and organisations (see table below) to ensure required input data is annually available to prepare the emission inventory. SEGES, the the central office for all Danish agricultural advisory services, shares data with DCE and Aarhus University, who update the input data in the Integrated Database Model (see Inventory practice: Integrated data management in Denmark) annually.

The cooperation between research and advisory services is of mutual benefit: it enables research to access actual and high quality data, whilst it enables advisory services to have actual core data to its disposal for high quality services and the provision of benchmarks to their farmers.

Institute	Key data/information collected
Statistics Denmark – Agricultural Statistics	• Livestock production • Milk yields • Slaughtering data • Export of live animals – poultry • Land use • Crop production • Crop yields
Danish Centre for Food and Agriculture (DCA), Aarhus University	• N-Excretion • Feeding plans • Animal growth • Use of straw for bedding • N-content in crops • Modelling of data regarding N-leaching/runoff • NH3 emission factor
SEGES	• Housing type (until 2004) • Grazing situation • Manure application time and methods • Estimation of extent of field burning of agricultural residues • Acidification of slurry

Further resources:
Denmark NIR 2017

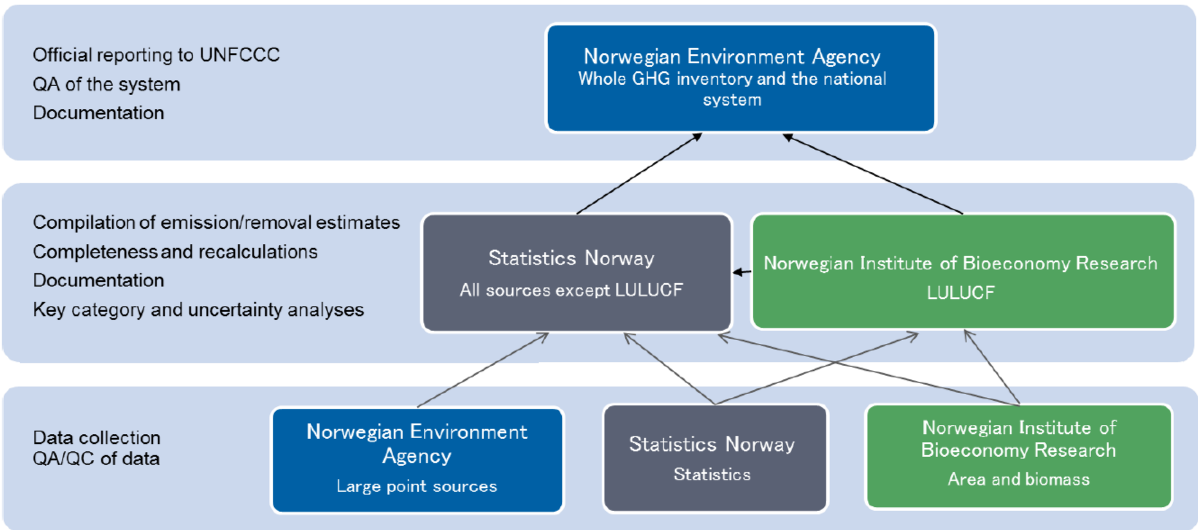
Inventory practice: Institutional arrangements for compilation of Norway's livestock emissions inventory

Tags: Institutional arrangements | Planning | Europe

Country context: Norway's methodology for Tier 2 estimation of cattle emissions is structured around the availability of activity data in the TINE BA Cow Recording System (see Inventory Practice: The role of cow recording systems in Norway's Tier 2 approach). This system collects data on individual milk production and feeding for dairy cows, and age at slaughter, carcass weight, and average daily gain for beef cattle. This well-defined source for most activity data required simplifies Norway's centralized compilation of the GHG inventory for cattle.

Institutional arrangements:

Compilation of Norway's inventory is the responsibility of three institutions: The Norwegian Environment Agency, Statistics Norway and the Norwegian Institute of Bioeconomy (NIBIO). Statistics Norway is responsible for the calculation of emissions from the agriculture and several other sectors. To ensure that the institutions comply with their responsibilities, Statistics Norway and NIBIO have signed agreements with Norwegian Environment Agency as the national entity. Through these agreements, the institutions are committed to implementing the QA/QC and archiving procedures, providing documentation, making information available for review, and delivering data and information in a timely manner to meet the deadline for reporting to the UNFCCC.



Inventory compilation process:

The three institutions involved agree a "milestone" production plan (Table 1), and each institution prepares their corresponding plan. Sector experts at Statistics Norway obtain data on animal populations and performance parameters recorded in the TINE BA Cow Recording System. Once data has been collected and QA/QC activities conducted, data is documented and archived separately by each of the three institutions. The archived information includes all input data, all estimated emissions, common reporting format tables, all technical documentation and details of any recalculations. The archiving systems used by each institution are consistent, which enables consistent QA/QC procedures to be applied.

Table AV-1 Milestone inventory production plan (indicative dates)

	Responsible	Deadline
Consideration of methodological changes needed for the next year's reporting, including those based on the review report from last year's reporting cycle	Norwegian Environment Agency	February 1st
Agreement on major methodological changes needed for next year's reporting	All	May 15th
Emission data from large industrial plants sent to Statistics Norway	Norwegian Environment Agency	October 15th
All non-LULUCF data collection completed	Statistics Norway	November 1st
LULUCF area data collection for the previous calendar year completed	Norwegian Institute of Bioeconomy Research	December 1st
National publishing of official statistics on emissions to air[1]	Statistics Norway	December
QA/QC of the emission estimates from the official statistics to air for use in the emission inventory	Norwegian Environment Agency	January 15th
All data entered into the CRF software	Statistics Norway and Norwegian Institute of Bioeconomy Research	February 1st
Review of documentation and necessary updates made[2]	All	March 15th
QA/QC of emission inventory in the CRF software completed	All	March 15th
NIR first draft	Norwegian Institute of Bioeconomy Research and Norwegian Environment Agency	March 15th
QA/QC reports sent to the Norwegian Environment Agency	All	March 30th
NIR finalized	Norwegian Environment Agency	April 13th
QA/QC report finalized	Norwegian Environment Agency	April 13th
Formal approval of the inventory for the purpose of reporting	Norwegian Environment Agency	April 13th
Reporting	Norwegian Environment Agency	April 15th

[1] The official statistics on emissions to air have a different aggregation of emissions than the greenhouse gas emission inventory reported to the UNFCCC. However, the activity data, emission factors and calculation methodologies are the same.

[2] This point includes internal documentation in all institutions as well as external documentation in the Norwegian Institute of Bioeconomy Research and Statistics Norway.

Further resources:

Norway NIR 2017

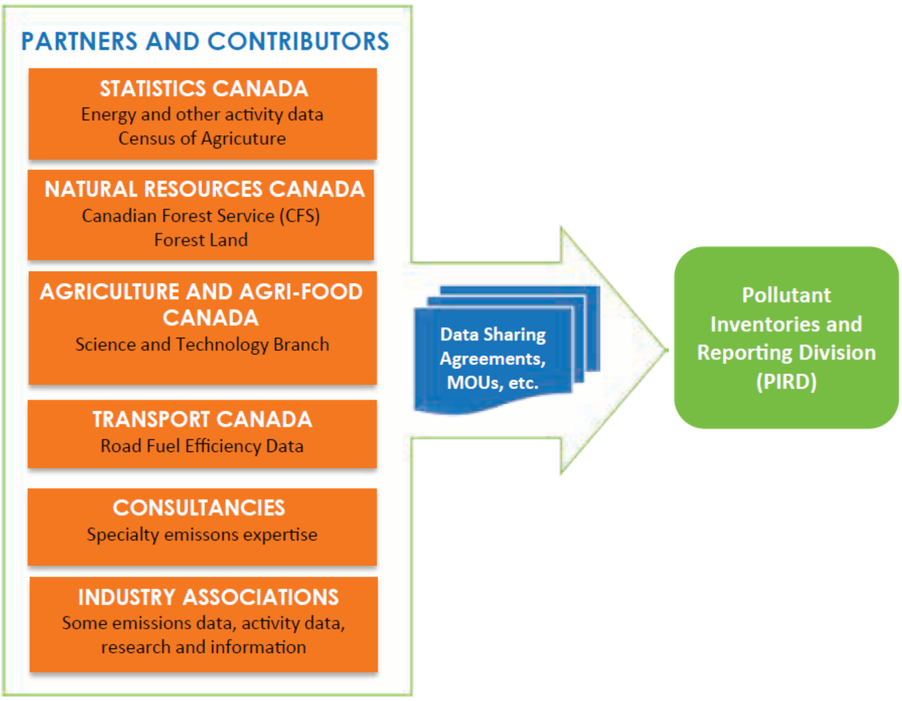
Inventory practice: Institutional arrangements for compilation of Canada's livestock emissions inventory

Tags: Institutional arrangements | North America

Country context: Canada's inventory estimates for cattle emissions are based in part on prior research that established typical management practices and performance of cattle in different production systems in each province (see Inventory Practice: Structured elicitation of expert judgement in Canada's initial Tier 2 inventory, and Inventory Practice: Structured elicitation of expert judgement on manure management practices in Canada). The main activity data required to compile the annual inventory are livestock population numbers and data on milk yields for dairy cattle and carcass weight for beef cattle.

Institutional arrangements:
Environment and Climate Change Canada is the federal agency responsible for preparing and submitting the national inventory to the UNFCCC. Canada's inventory is developed, compiled and reported annually by Environment and Climate Change Canada's Pollutant Inventories and Reporting Division. In order to facilitate inventory compilation using data from different sources, Environment and Climate Change Canada has developed numerous agreements with data providers and expert contributors. Agreements include partnerships with other government departments (e.g. Statistics Canada, Agriculture and Agri-Food Canada), and arrangements with industry associations, consultants and universities.

Figure 1–2 Partners and Contributors to National Inventory Arrangements



For compilation of the inventory of livestock emissions, Statistics Canada provides data on livestock populations. Milk yield data are reported by Agriculture and Agri-Food Canada, which also publishes beef cattle carcass weight data in the basis of data collected by the Canadian Beef Grading Agency. In addition, Agriculture and Agri-Food Canada provides scientific support to the agriculture sector inventory, and numerous researchers have participated in some extensive reviews, validation of the parameter values selected and validations of the Tier 2 models used by comparing measured and observed emissions using Canadian data.

Further resources:
Canada (2017) NIR

Inventory practice: Institutional arrangements for compilation of Finland's livestock emissions inventory

Tags: Institutional arrangements | Europe

Institutional arrangements: Statistics Finland is responsible for Finland's greenhouse gas inventory. Statistics Finland maintains agreements between the inventory unit and expert organisations that produce the emission estimates and maintain related documentation. The agreement between Statistics Finland and expert organisations define the division of responsibilities and tasks, including those related QA/QC. They also specify the procedures and schedules for the annual inventory process coordinated by Statistics Finland. All the expert organisations are represented in an inventory working group. The working group facilitates collaboration and communication between the inventory unit and the experts producing the estimates for the different reporting sectors, and ensures the implementation of the QA/QC and verification process of the inventory. The agriculture sector emissions inventory is compiled by Natural Resources Institute Finland (LUKE), including estimates for enteric fermentation and both methane and nitrous oxide from manure management. LUKE is the agency that publishes livestock population data and other farm management data, such as animal weight, average daily weight gain, milk production per dairy cow and suckler cow, pregnancy, duration on pasture and manure management data. The resource for the participation of LUKE are channelled through the Ministry of Agriculture and Forestry so that the data collected in the process of public administration duties can be used in the emission inventory.

During the inventory compilation, the calculation sheets and data related to inventory are stored in personal folders in the server maintained by the information services of the Natural Resources Institute Finland (Luke). The folder structure is similar for each inventory year, which makes data management easier. A limited group of persons have access rights to the files. After the compilation, the results and relevant data reported to Statistics Finland and are archived in LUKE's write-protected electronic archive.

Further resources:
Finland (2017) NIR

Inventory practice: Institutional arrangements for compilation of the UK‘s livestock emissions inventory

Tags: Institutional arrangements | Europe

Institutional arrangements:

The UK's greenhouse gas inventory is compiled and maintained by a consortium of institutions under contract to the Department for Business, Energy and Industrial Strategy (BEIS). The consortium is led by Ricardo Energy & Environment, which is responsible for producing the emissions estimates for energy, industrial processes and waste sectors, and for inventory planning, data collection, QA/QC and inventory management and archiving. Agricultural sector emissions (CRF sector 3) are produced by Rothamsted Research, under contract to the Department for Environment, Food & Rural Affairs (DEFRA).

As the contractor responsible for the agriculture inventory, Rothamsted Resarch is responsible for:

- activity data, methods, emission factors and emission estimation;
- preparing and developing the agriculture inventory and delivering on time for incorporation into national inventory;
- delivering the finalised GHG emissions data to Ricardo Energy & Environment;
- maintaining documentation and archiving of models and procedures used; and
- participating in sectoral expert panels as required.

Ricardo Energy & Environment are responsible for checking consistency between outputs.

The UK has established a National Inventory Steering Committee (NISC) as a cross-government body. The NISC is tasked with the official consideration and approval of the national inventory prior to submission to the UNFCCC. This pre-submission review is done at a NISC meeting prior to the finalisation of the inventory, and any recalculations to the inventory are presented and discussed at this meeting. The NISC also assists the BEIS GHG inventory management team to manage and to prioritise the over-arching inventory QA, facilitate review and improvement, and improve communication between inventory stakeholders across government departments. Members of the Steering Committee include the Inventory Agency team at Ricardo Energy & Environment, other contractors, plus appropriate sector, legal and economic experts. These experts are responsible for reviewing methodologies, activity data, emission factors and emission estimates at a sectoral level and report their findings and recommendations to the steering committee on a regular basis. The committee is responsible for ensuring that the inventory meets international standards of quality, accuracy and completeness, and is delivered on time each year to the EU Monitoring Mechanism Regulation and the UNFCCC.

The NISC is responsible for agreeing the priorities for the UK GHGI improvement programme. The NISC meets twice a year to discuss the outcomes of recent peer, internal and expert reviews and to agree the prioritisation, funding, implementation and review of items on the UK inventory improvement programme.

The Key Category Analysis and the uncertainty analysis, qualitative analysis from inventory experts and recommendations from reviews of the UK GHG inventory are used as guidance to help the members of the NISC make decisions on which improvements are the most important. Key categories with high uncertainty are given priority over non-key categories or categories with a low uncertainty. The annual inventory review feedback from the UNFCCC and outcomes from QA/QC checks and reviews carried out under the MMR and ESD, as well as sector-specific peer- or bilateral review findings are also considered to guide decisions on UK GHGI improvement priorities.

Further resources:

UK NIR 2017

Inventory practice: New Zealand’s agriculture inventory advisory panel

Tags: Expert review | commissioned reviews | continuous improvement | institutional arrangements | Oceania

Country context: Grassland-based animal husbandry makes major contributions to New Zealand’s economy. The country’s GHG inventory has used a Tier 2 approach for cattle, small ruminants and deer since the early 1990s. Since then, New Zealand’s Tier 2 livestock inventory has undergone three major stages of development (see Country Inventory Case Study New Zealand). The inventory has maintained its current structure since 2009, and within that structure, improvements in emission estimates continue to be made. The Agricultural Inventory Advisory Panel plays a key role in the continuous improvement process.

Institutional arrangements: The Climate Change Response Act 2002 names the Ministry for the Environment as the agency in New Zealand responsible for compilation of the national GHG inventory. The MoE calculates estimates of emissions for the solvent and other product use sector, waste sector, emissions and removals from the LULUCF sector, and coordinates inputs from other sectors. The Ministry for Primary Industries (MPI, formerly Ministry of Agriculture and Forestry) compiles the agriculture sector inventory. This is supported by research conducted by public research institutes and universities. In 2009, MPI established an advisory panel that meets annually to deliberate on and recommend improvements to the agricultural inventory. The panel assesses peer-reviewed reports and papers providing evidence for proposed changes to the inventory, and advises whether the proposed changes are scientifically robust and meet the reporting guidelines. The panel advises MPI of its recommendations, and MPI must approve the recommendations before the recommendations can be implemented in the national inventory calculations. Hence, the role of the panel is advisory.

The panel is made up of representatives from the Ministry of Agriculture and Forestry, the Ministry for the Environment, and science representatives from the Royal Society of New Zealand, the New Zealand Agricultural Greenhouse Gas Research Centre, and experts on methane emissions (from New Zealand Methanet) and nitrous oxide emissions (from New Zealand N_2Onet), which are groups of national experts in the areas of agricultural inventory methane and inventory nitrous oxide emissions respectively.

Based on key information needs identified by the panel and MPI, the ministry commissions reviews and other analysis to inform decisions about inventory improvements. The reviews and analysis are presented to the panel in the form of reports or papers. Each report or paper includes specific recommendations for changes to the inventory and/or further needs for research and analysis, as well as the supporting evidence for these recommendations. The papers are peer-reviewed by the panel members, who submit review reports. The MPI then prepares a briefing paper, which summarizes the main findings of the report and the peer-reviews, and sets out the recommendations to be noted, discussed or decided during the annual meeting of the panel. The panel assesses if the proposed changes have been rigorously assessed and if there is sufficient scientific evidence to support the recommendations made. Recommendations are decided by voting. If a panel member was involved in conducting the commissioned study, they are recused from voting. The minutes of the meeting and the recommendations made are recorded and posted along with the panel briefings and other reports on the MPI website: https://www.mpi.govt.nz/news-and-resources/open-data-and-forecasting/greenhouse-gas-reporting/agricultural-inventory-advisory-panel/

The reports commissioned by MPI mostly involve review of available data, including published scientific journal articles, as well as unpublished data from research and industry sources. In some cases, commissioned reports also involve the collection of new primary data, for example where suitable data is unavailable. Topics deliberated by the advisory panel in recent years have included:

- Recommendations for calculating national dairy sector emissions on the basis of regional estimates;
- Revisions to ewe and beef cow live weight estimates (see Inventory Practice: Improving estimates of cattle live weight in New Zealand);
- Revised methodologies for calculating N_2O emission factors;
- Revised equations for methane emissions from anaerobic effluent ponds;
- Revisions to parameters used in the inventory for emissions from deer populations;

- Revised uncertainty estimates; and
- Revisions to the livestock population model used in the inventory.

Further resources:
MPI Agricultural Inventory Advisory Panel: https://www.mpi.govt.nz/news-and-resources/open-data-and-forecasting/greenhouse-gas-reporting/agricultural-inventory-advisory-panel/

Inventory practice: Estimating milk yields in Luxembourg

Tags: Milk yield | Europe

What data needs were addressed? Estimating milk yield per cow per year.

Why was the data needed? Luxembourg does not have detailed records on milk yields per cow per year, so needed to estimate milk yields from available data.

Methods used: calculation

How was the data gap addressed?
The national inventory uses the official estimate of milk production. This is calculated from the official amount of milk output by producers. It is calculated by Luxembourg Rural Economy Service (SER) by adding up:
(1) the amount of milk collected by the dairy industry directly from the farmers;
(2) the amount of milk and milk products directly sold by the farmers; and
(3) milk consumption on farm, including consumption by farming families and by animals.
Luxembourg has a population of 6000-7000 dairy cows and about 3000 suckler cows. The estimate of milk yield per head first assumes that suckler cows give 3500 kg per year on average. Since management practices have not changed over time, this value remains unchanged. The milk output due to suckler cows is calculated by multiplying the suckler cow population by 3500 kg. The remaining output is then divided by the number of dairy cows to produce an average annual milk yield per dairy cow.

Total milk output in Luxembourg has increased by about 23% between 1990 and 2015, while the dairy population has fallen by 20%. Hence, the implied emission factor for dairy cows has increased by 19% over this period.

Further resources:
Luxembourg NIR 2017

Inventory practice: Improving estimates of cattle weights in New Zealand

Tags: Expert review | animal weight | cattle | Oceania

Country context: Grassland-based animal husbandry makes major contributions to New Zealand's economy. The country's GHG inventory has used a Tier 2 approach for cattle, small ruminants and deer since the early 1990s. Since then, New Zealand's Tier 2 livestock inventory has undergone three major stages of development (see Country Inventory Case Study New Zealand). The inventory has maintained its current structure since 2009, and within that structure various improvements in emission estimates have been made (see Inventory practice: New Zealand's Agriculture Inventory Advisory Panel).

What data needs were addressed? Improved estimates of live weights for ewes and beef cows.

Why was the data needed? New Zealand's inventory is based methane emissions model that estimates emissions on the basis of estimated energy and feed intakes. Since most energy consumed by breeding animals is used for maintenance, animal live weight is closely related to energy and feed intake estimates. Feed intake is estimated on the basis of live weight, but estimation of live weight in the model is done using data on carcass weight and an assumed carcass ratio (i.e. dressing out percentage). A review of the national inventory model (Muir *et al.,* 2008) suggested that the ewe and beef cow carcass or live weight estimates and carcass ratios used in the model were based on limited data and assumptions that might lead to significant errors in the inventory estimates.

Methods used: Expert review of available data, including slaughter weight data, and collection of primary data.

How was improved data derived? New Zealand has an advisory panel that meets annually to deliberate on and recommend improvements to the agricultural inventory (see Inventory practice: New Zealand Inventory Advisory Panel case study). Based on key information needs identified by the panel and the responsible ministry (the Ministry for Primary Industries), the ministry commissions reviews and other analysis to inform decisions about inventory improvements. In 2008, a review of the inventory model (Muir et al 2008) suggested that the ewe and cow live weight estimates used in the model were based on limited data and assumptions that might lead to significant errors in the inventory estimates. The ministry commissioned a review of ewe and beef cow live weight estimates used in the model. The review assessed the appropriateness of the data and assumptions used in the inventory model by comparing the inventory live weight estimates with the best available published and unpublished data (including new data collected for the review) on both live weights and carcass ratios (i.e. killing out percentage). Because live weight data is typically collected either at mating time or at culling, the review also assessed the implications of the timing of data collection of providing an estimate of annual average live weight.

For beef cows live weight, the reviewers searched records in available journal publications, but most publications were found to be of limited use as they either reported results from feeding trials that are not representative of commercial production conditions, or reported on breeds that are not typical of the national herd. However, unpublished live weight data on 2100 cows was available from researchers. In addition, live weight of breeding cows was measured on 12 farms in 2009 and 2010 using breeds that are more representative of the national herd. Live weights were measured at weaning and pregnancy testing because this is when farmers identify animals for culling. By collecting data at this time, it was also possible to examine any differences in live weights between the culled animals and those that remained in the herd. For the culled animals, data on carcass weights was also collected to provide an estimate of the carcass ratio. The estimated carcass ratio was 42.6%, slightly lower than the 45% assumed in the inventory model.

Different sources of live weight estimates were compared. The most representative datasets were deemed to be the unpublished data from Landcorp (the state owned livestock enterprise), a research project previously funded by the ministry, and from the surveys conducted as part of the review. The first two data sources reported carcass weights, to which the carcass ratio estimated by the review survey was applied. The latter data source reported measured live weights. All these data sources reported heavier live weights that that used in the inventory model. The average across these data sources was taken as the basis for recommending that the inventory should use a figure of 547 kg for 2009/10.

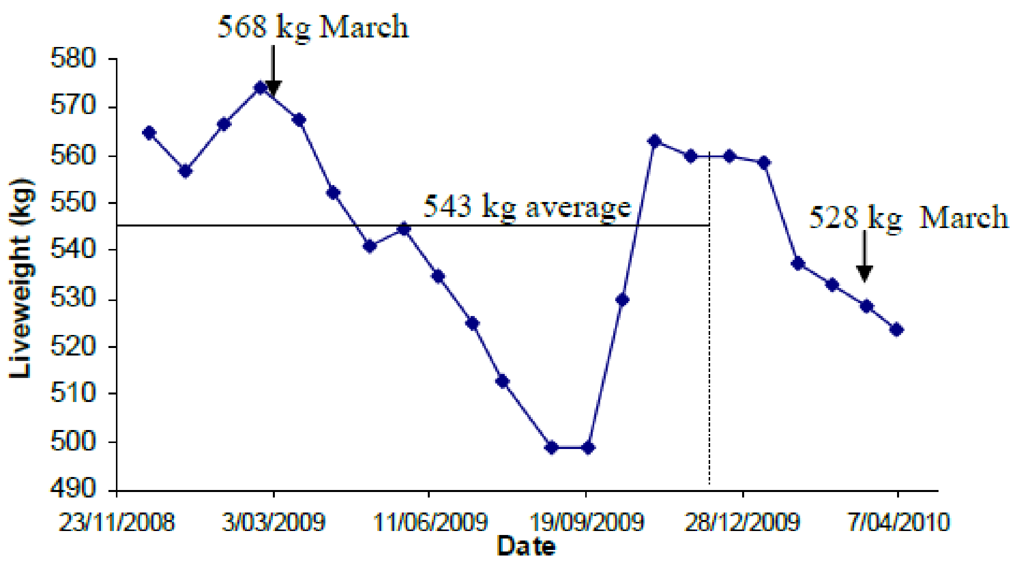
Table 1: Live weight and carcass weight estimates for beef cows

Dataset	Herd cow LW (kg)	Cull cow LW (kg)	Carcass weight (kg)	Carcass ratio (%)
Landorp (2007/8)	568*		242	
Ministry study (2007/8)	537*		229	
Review survey (2008/9)	510	527	221	41.4
Review survey (2009/10)	573	555	252	43.9
Inventory model (2009/10)	451			45
Suggested revision	547		236	42.6

* Estimated from measured carcass weight

Cow live weight at pregnancy testing or weaning (i.e. end of summer) is often the annual maximum live weight, and slaughter mostly takes place over the summer, when live weights tend to be greater. If the live weight at pregnancy testing or culling is used, this would tend to overestimate annual average live weight. Unpublished data from one researcher and one farm was available to describe the seasonal change in live weight and estimate the extent to which slaughter data would overestimate annual average live weight (Figure 1). This analysis suggested that using slaughter data would tend to overestimate annual average live weight by 5-10 kg.

Figure 1: Liveweights in mixed aged beef cows (n-492) in Northland farm



Source: Muir and Thomson (2011)

In addition to estimating live weight in 2009-10, live weight estimates for the inventory would have to be applied to the inventory time series going back to 1990. Data was available on carcass weight for almost 100,000 beef cows slaughtered by Landcorp between 1997/98 and 2008/09. Applying the carcass ratio estimated by the review, a live weight time series was constructed that suggested an annual average increase in live weight of 8.5 kg/year. Extrapolating this back to 1990 suggests that in 1990/1991 the average beef cow would have weighed 402.5 kg, which is slightly higher than the 378 kg assumed for that year in the inventory model.

Similar analysis was conducted for ewes, using published, unpublished and newly collected live weight data, assessing the representativeness of the breeds weighed and the implications of the timing of weight measurements for deriving annual average live weight estimates.

The revised estimates were then applied to New Zealand's inventory from 2012 onwards.

Further resources:

Pickering, A. (2010) MAF Policy Agricultural Inventory Panel Meeting 17 August 2010.

Muir, P.D., Thomson, B.C., (2011) Better estimation of national ewe and beef cow liveweights. Report prepared for the Ministry of Agriculture and Forestry

Muir, P.D., Thomson, B.C., Hegarty, R.S. (2008) A Review of New Zealand's National Methane Inventory Model. Report prepared for the Ministry of Agriculture and Forestry

IPCC Guidance (IPCC 2006 Vol 4 Ch 10 p.10.12)

Inventory practice: Verification of livestock emission factors in South Africa

Tags: QA/QC | verification | cattle | Africa

What data needs were addressed? Verification of country-specific emission factors.

Why was the data needed? When South Africa first developed country-specific emission factors, Australian models of enteric fermentation were adopted, because conditions in Australia and South Africa are similar. Emission factors for South African livestock were developed by Du Toit et al (2013a, 2013b, 2013c, 2013d) using Australian models for estimating enteric fermentation from ruminants, pseudo-ruminants and monogastrics. The emission factors were estimated for the year 2010. The resulting emission factors were significantly different from those recommended by the IPCC for the African continent. Therefore, a method to compare emission factors and justify the choice of emission factor was needed.

Methods used: comparison with other emission factors

How was the data need addressed? South Africa's National Inventory Report (2014) compared the estimated emission factors with IPCC default values for Africa, Oceania and Western Europe and explored the underlying productivity data used to derive the IPCC default emission factors.

Comparison of emission factors showed that South Africa's country-specific EFs were in the same range as the defaults for Oceania and Western Europe, but were not similar to defaults for Africa. This is explained by the productivity data. Milk production in South Africa in 2010 wwas 14.5 kg per day, much higher than the assumed 1.3 kg per day given for Africa. Cattle weights were also much higher (333 – 590 kg, compared to 275 kg for Africa). Pregnancy and DE percentages were also higher than those used in the IPCC default values.

Table 5.4: Sector 3 AFOLU – Livestock: Comparison between the productivity data used and EF calculated in this inventory and the IPCC 2006 Guideline default values.

Livestock category	Parameter	Value used in this study (2010)	IPCC 2006 default values (Table 10.11, 10A.1, 10A.2)		
			Africa	Oceania	Western Europe
Dairy cattle	Milk production (kg $head^{-1}$ yr^{-1})	6,015	475	2,200	6,000
	Milk production (kg day^{-1})	14.5	1.3	6	16.4
	Cattle weight (kg)	322 – 590 (heifer - mature cow)	275 (mature cow)	500	600
	Pregnancy (%)	58	67	80	90
	DE%	76	60	60	70
Other cattle	Cattle weight (kg)	Communal: 360 – 462 (cow - bull); Commercial: 475 – 733 (cow - bull)	200 – 275 (cow - bull)	400 – 450 (cow - bull)	400 – 600 (bulls)
	Pregnancy	24 – 49	33	67	No value given
	DE%	55 – 80	55	55	60 – 65

Further resources:

IPCC 2006 Vol 1 Ch 6 (quality assurance, quality control and verification)

South Africa NIR 2014 https://unfccc.int/files/national_reports/non-annex_i_parties/biennial_update_reports/application/pdf/rsaghg_bur1.pdf

Du Toit, C. J. L., and W. A. Van Niekerk. "Direct methane and nitrous oxide emissions of South African dairy and beef cattle." *South African Journal of Animal Science* 43, no. 3 (2013): 320-339.

Du Toit, C. J. L., and Willem A. Van Niekerk. "Direct methane and nitrous oxide emissions of monogastric livestock in South Africa." *South African Journal of Animal Science* 43, no. 3 (2013): 362-375.

Du Toit, C. J. L., H. H. Meissner, and Willem A. Van Niekerk. "Direct greenhouse gas emissions of the game industry in South Africa." *South African Journal of Animal Science* 43, no. 3 (2013): 376-393.

Du Toit, C. J. L., Willem A. Van Niekerk, and H. H. Meissner. "Direct greenhouse gas emissions of the South African small stock sectors." *South African Journal of Animal Science* 43, no. 3 (2013): 340-361.

Inventory practice: Choice of emission factor for manure management in Japan

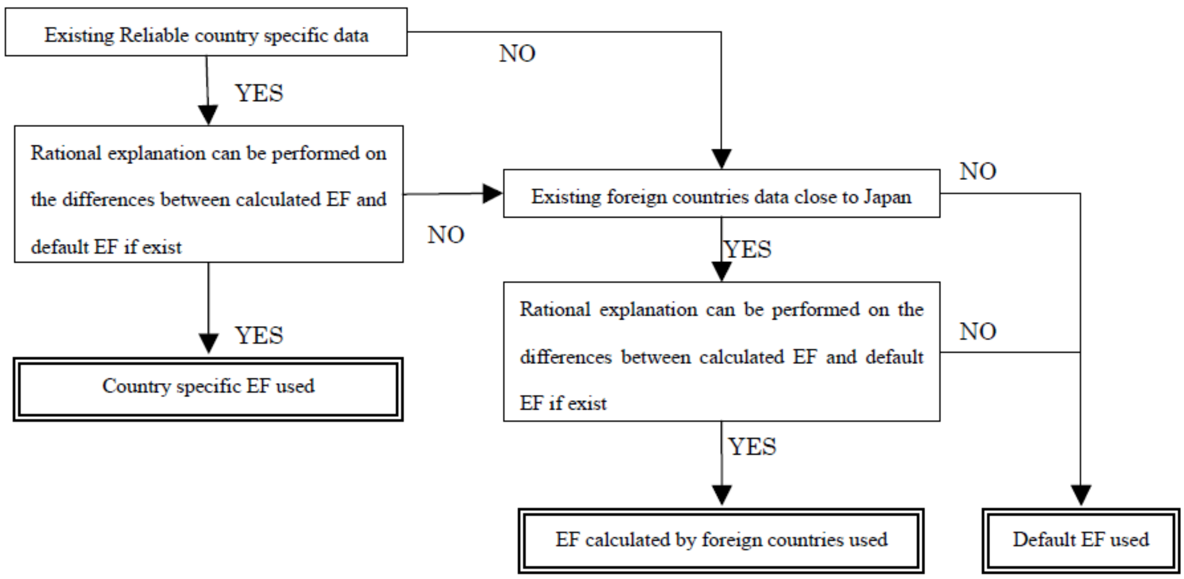
Tags: Decision tool | manure management | cattle | pigs | poultry | Asia

What data needs were addressed? Choice of emission factor for methane manure management emissions.

Why was the data needed? Japan has a considerable body of data from direct measurements of manure management methane emissions, and early inventories used these measurement results. In order to improve the reliability of the inventory, in NIR 2006 a decision tree was applied to guide the choice of data for emission factors.

Methods used: decision tree

How was the data need addressed? The 2006 IPCC Guidelines note that while using direct measurements of emissions to parameterize models for estimation of emission factors may be a good approach, measurements are difficult to conduct, and require significant resources and expertise, and equipment that may not be available. Direct measurements are not required for good practice as defined by the IPCC. Hence, Tier 1 and Tier 2 approaches are proposed as alternatives. Japan has a considerable body of data from direct measurements. However, not all the measured results were similar to IPCC default values. Therefore, a decision-tree was developed to guide the selection of emission factors for manure management emissions (Figure 1).



Source: NIR 2018

As a result of applying the decision tree, a mixture of IPCC default values, country-specific values and values based on research in other countries is used (Table 1). By continually applying the decision tree to research results newly available in each year, Japan has gradually replaced some EFs with country-specific values, but continues to use default values where better estimates are unavailable.

Table 1: Manure management methane emission factors for cattle, pigs and poultry in Japan's national inventory

treating method		Daily Cattle		Non-daily cattle		Swine		Hen, Broiler	
12. Pit storage		3.90 %	D	3.00 %	D	8.7 %	D	—	—
13. Sunlight drying		0.20 %	J	0.20 %	J	0.20 %	J	0.20 %	J
14. Other	13a. Thermal drying	0 %	Z	0 %	Z	0 %	Z	0 %	Z
	13b. Composting (feces)	0.044 %	D	0.034 %	D	0.097 %	D	0.14 %	J
	13c. Deposition	3.80 %	J	0.13 %	J	0.16 %	J	0.14 %	J
	13d. Incineration	0.4 %	O	0.4 %	O	0.4 %	O	0.4 %	O
	13e. Composting (feces and urine mixed)	0.044 %	D	0.034 %	D	0.097 %	D	—	—
	13f. Wastewater management	0.0087%	D	0.0067%	D	0.019%	D	—	—

Note: D = IPCC default; J = Japan; O = other countries; Z = not applicable.
Source: NIR 2006

Further resources:
Japan NIR 2006, 2018
2006 IPCC Guidelines Vol 4, Ch 10, 10.4.2

Inventory practice: Estimating a time series for cattle feed digestibility in Moldova

Tags: Expert judgement | digestibility | cattle | Europe

What data needs were addressed? Estimation of a time series since 1990 for feed digestibility when digestibility data for previous years is missing.

Why was the data needed? When adopting a Tier 2 approach, the approach should be applied to the whole time series back to the base year (1990), but historical data on feed digestibility was missing, so alternative methods were needed.

Over recent decades, fodder and feed production in the Republic of Moldova has been affected by both general socio-economic conditions and natural conditions. Prior to the early 1990s, cattle production 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 a consequence of poor organization of fodder production and inappropriate animal feeding and maintenance conditions. 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.

Methods used: expert opinion

How was the data gap addressed? The IPCC 1996 Guidelines (Reference Manual, Ch 4, 4.16) provides representative feed digestibility values for different types of livestock: 50-60 per cent for crop by-products and range lands, 60-75 per cent for good pastures, good preserved forages, and grain supplemented forage-based diets and 75-85 per cent for grain-based diets fed in feedlots. 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 (Table 1).

Table 1: 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

Further resources:
Republic of Moldova (2014) NIR
IPCC 1996 Reference Manual Ch 4
IPCC 2006 Guidelines Ch 10

Inventory practice: Use of feed tables to estimate gross energy in Lithuania

Tags: feed tables | milk yield | dairy cattle | Europe

What data needs were addressed? Estimating gross energy intake for dairy cattle.

Why was the data needed? Lithuania's inventory points out that gross energy and milk yield have a clear positive relationship. Estimation of gross energy in the inventory can be simplified if standards are used to relate annual milk yield data to gross energy intake.

Methods used: feed standards

How was the data gap addressed? Gross energy estimates for dairy cattle are based on feed standards. National research has established that gross energy intake is related to crude protein, crude fat, crude fibre and nitrogen-free extracts in feed, and identified a relationship between these feed contents and milk yield (Table 5.14). Gross energy is estimated as a function of these feed contents:

$$GE = 0.0239 \cdot CP + 0.0398 \cdot CFat + 0.0201 \cdot CFiber + 0.0175 \cdot NFE$$

where:
GE – gross energy, MJ / kg in DM;
CP – crude protein, g/kg in DM;
CFat – crude fat, g/kg in DM;
CFibre – crude fibre, g/kg in DM;
NFE – nitrogen-free extracts, g/kg in DM.

Since the nutrition standards have established the relationship between milk yield and dietary nutrients, inventory estimates of gross energy intake can be made using only data on milk yield. Milk yield values between those shown in the table are interpolated.

Table 5-14. Nutrition standards for dairy cattle

	Quantity of milk (4% milk fat), kg/day		
	10	**15**	**20**
Dry matter, kg	12.7	15.1	17.0
Crude protein, g	1,524	2,038	2,550
Crude fat, g	279	362	459
Crude fiber, g	3,048	3,473	3,740
Nitrogen-free extract	6,350	7,420	8,990

Source: Lithuania NIR 2017

Further resources:
Lithuania (2017) NIR

Inventory practice: Use of national feeding standards to estimate net energy requirements in Hungary

Tags: Feed tables | cattle | Europe

What data needs were addressed? Estimating gross energy intake for dairy cattle.

Why was the data needed? Hungary's national feed nutrition standards (Hungarian Nutrition Codex, 2004) are based on the NRC equations that underlie the IPCC model for enteric fermentation. However, there are some differences in the underlying methodology. This means that there are some differences in gross energy estimations made using the IPCC method and the Hungarian feed standarsd.

Methods used: national energy balance model.

How was the data gap addressed? The main difference between the Hungarian and the IPCC model is that the Hungarian model does not differentiate between net energy for maintenance and activity, but takes both energy requirements into account as net energy for maintenance. Hungary's inventory compilers decided to estimate these separately using Eq. 10.5 of 2006 IPCC Guidelines. Calculation of net energy for lactation also differs from the IPCC methodology. Inventory compilers applied both equations andfound that the Hungarian standards gave higher values than the IPCC model. They decided to calculate net energy for lactation using the Hungarian standards, on the grounds that this is more reliable for common Hungarian breeds. The equations used for net energy for pregnancy were different, but the result of calculation was very similar, so the simpler IPCC equation was applied. Finally, for converting net energy requirements into gross energy intake, data on diet composition derived from a national Farm Accountancy Data Network (FADN), and digestibility values for the different dietary compoents were taken from the 'feed database' provided in the Hungarian Nutrition Codex (2004). This database contains results of laboratory measurements for feeds in Hungary.

Further resources:
Hungary (2018) NIR

Inventory practice: Improving feed digestibility estimates in Latvia

Tags: Expert judgement | commissioned research | digestibility | cattle | Europe

What data needs were addressed? Producing a country-specific estimate of cattle feed digestibility.

Why was the data needed? Prior to 2017, Latvia had no country-specific data on feed digestibility and the GHG inventory used 65%, which is the mid-range of the representative values for pasture-fed cattle in the 2006 IPCC Guidelines (Ch. 10, Table 10.2).

Methods used: commissioned research, expert opinion

How was the data gap addressed? The government of Norway operated a grant programme to reduce disparities between members of the European Economic Area. In the programme agreement on national climate policy with Latvia, the pre-defined project "Development of the National System for Greenhouse Gas Inventory and Reporting on Policies, Measures and Projections" included funding for improving estimates of feed digestibility. The research was conducted by the Latvia University of Agriculture (Degola et al. 2016). Feed samples were taken from 38 farms in different regions of the country at different growth stages over 2015. The selection of farms was undertaken to represent farms with different scales of dairy cattle production. The samples covered hay, silage, haylage and total mixed ration. The samples were analyzed at the university's Scientific Laboratory of Agronomic Analysis. Chemical analysis of feed was conducted for dry matter (DM) %, crude protein (CP) %, insoluble protein, %, soluble protein, %, undegraded intake protein (UIP) %, crude fiber (CF) %, acid detergent fiber (ADF) %, neutral detergent fiber (NDF) %, ash %, Ca and P %, according ISO 5983, ISO 6490/2 and ISO 6491 standards. Digestibility was determined using the cellulase method and by calculation of net energy for lactation.

The average determined digestibility of forage for natural meadow hay was 52.3±4.3% and 53.8±5.2% for cereal grass hay; for grass silage with preservative 65.2±6.1%, without preservative 62.8±4.9%; and for corn silage, respectively 71.1±0.6%, 68.2±3.1%; for haylage 62.6±4.1%, for TMR 71.7±5.7%.

For the national GHG inventory, interviews were conducted with agricultural and academic experts to identify the typical feed rations for dairy cows and other cattle. This suggested that the feed ration of dairy cows consists on average of 71% grass forage and 29% concentrates based on dry matter intake. Feed ration composition for other cattle types were also estimated. The results of cattle feed quality analysis and feeding ration composition estimates were combined, leading to a feed digestibility estimate of 67% for dairy cows in 2015. Considering that the proportion of concentrates in dairy cow diet had been gradually increasing, it was decided to use a digestibility value of 66% for dairy cows in the period 2010-2014. For other cattle, a value of 65% was estimated.

Furthermore, correlation analysis between digestibility determined using the cellulose method and the calculation method found a good correlation, leading to the conclusion that it is not necessary to determine forage digestibility in the laboratory with the cellulase method, but the formula DDM, % = 88.9 – (0.779 x ADF %) can be used, where the digestibility is calculated from the ADF content in feed.

Further resources:

Latvia NIR 2017
IPCC 2006 Guidelines Ch 10, 10.14
Degola, L., Trupa, A. and Aplocina, E., 2016. Forage quality and digestibility for calculation of enteric methane emission from cattle. In *15th International Scientific conference „Engineering for Rural Development": Proceedings* (pp. 456-461). Available at http://tf.llu.lv/conference/proceedings2016/Papers/N084.pdf

Inventory practice: Accounting for the effects of increased concentrate use on gross energy intake and digestible energy

Tags: digestibility | cattle | Europe

What data needs were addressed? Estimating digestible energy when concentrate feed consists of a greater proportion of dairy cattle diet.

Why was the data needed? Dairy cattle in Slovenia are fed a greater proportion of concentrate in their diet than other types of cattle. When estimating gross energy, information on the concentration of net energy for lactation is critical to avoid under- or overestimation of gross energy intake.

How was the data need addressed? Slovenia applies the IPCC Tier 2 model for dairy cattle, but has introduced refinements to the model and implements the model in a country-specific manner.

Step 1: Estimation of net energy requirements for the maintenance (NEm), activity (NEa), milk production (NEl) and pregnancy (NEp). These are determined following the IPCC guidance and using the default IPCC coefficients.

Step 2: Estimation of gross energy intake. For this, the concentration of net energy for lactation is estimated, considering energy concentration in the basal diet and the proportion of concentrates in the diet. The concentration of net energy for lactation in the diet was calculated as a quotient between the animal requirements for maintenance, milk production and pregnancy on the one hand and potential dry matter intake on another. National feeding standards were used to assess the requirements. Specifically, monthly milk recording data from 2000-2009 was used to construct more than 700,000 lactation curves, on the basis of which standard lactation curves at 500 kg intervals ranging between 3500 and 12000 kg were calculated. Based on daily milk yields and assumed concentrations of net energy for lactation in basal diet, the required proportions of concentrates in diets were estimated. Dry matter intake was then predicted on the basis of daily milk production, amount of concentrates and concentration of net energy for lactation in the basal diet, using equations developed by researchers in Germany (Gruber et al. 2005).

Step 3: Estimation of digestible energy: The estimated concentration of net energy for lactation was then transformed to organic matter digestibility (dOM) using an equation based on data in the German feeding tables (DLG 1997):

$$dOM = 24.12 + \text{net energy for lactation} \times 7.9.$$

Energy digestibility (DE%) was estimated as:

$$DE\% = dOM - 3.1.$$

The relation was obtained on the basis of equations presented in INRA (1989).

Step 4: Gross energy intake was then calculated using Equation 10.16 in IPCC (2006, Vol 4 Ch 10).

Further resources:

Slovenia NIR 2017
DLG 1997 Futterwertttabellen. Wiederkäuer. DLG Verlag, Frankfurt am Main, 1997, 212 p.
Gruber et al. 2005 https://www.raumberg-gumpenstein.at/cm4/de/forschung/publikationen/downloadsveranstaltungen/viewdownload/1789-3432-wt-entw-futteraufnahmeschaetzformel-milchkuehe/14144-schaetzung-der-futteraufnahme-bei-der-milchkuh.html
INRA Ruminant nutrition, Recomended allowance & feed tables, Paris, INRA, 1989, 389 pages

Inventory practice: Estimating digestible energy and methane conversion rates for feedlot cattle in the USA

Tags: Expert judgement | interpolation | digestibility | methane conversion rates | cattle | North America

What data needs were addressed? An estimate of digestible energy (DE as a % of GE [MJ/Day]) was required for feedlot cattle.

Why was the data needed? Diet composition for feedlot cattle in the USA has been changing rapidly as feedlots change their practices based on new nutritional information and changing feed availability. Therefore, values for DE and Ym in the USA's GHG inventory are adjusted over time.

Methods used: interpolation of available data, expert surveys, expert opinion, modelling

How was the data gap addressed? Feedlot diets are assumed to not differ significantly by region within the country, so a single set of national diet values is used each year.

For 1990, DE and Ym values used in the inventory were provided by a leading academic on methane production in cattle.

For 1991-1999, values were linearly extrapolated based on values for 1990 and 2000.

For 2000 onwards, values for Ym were estimated using the MOLLY model, as described in Kebreab et al. (2008). This model is a dynamic mechanistic model of nutrient utilization in cattle. Methane production is predicted based on hydrogen balance. Excess hydrogen produced during fermentation of carbohydrates and protein to lipogenic VFA (acetate and butyrate) is partitioned between use for microbial growth, biohydrogenation of unsaturated fatty acids, and production of glucogenic VFA (propionate and valerate). It is assumed that the remaining hydrogen is used for methanogenesis.

To run the MOLLY model, data on average diet feed compositions was taken from Galyean and Gleghorn (2001) for 2000 through 2006 and Vasconcelos and Galyean (2007) for 2007 onwards. These sources are an annual survey of consulting animal nutritionists. The survey is a postal or web-based survey, with respondent numbers generally between 19 and 31. The questionnaire asks the nutritionists to indicate, among other things:

- the % of dry matter contributed by different types of grain, grain by-products, roughage and other supplements to the cattle finishing diet,
- the recommended concentration of key nutrients in the diet for cattle at different growth stages,
- other management practices recommended to feedlots (e.g. diet adjustment periods).

DE values and other parameters required as inputs to the MOLLY model are estimated from the survey responses. For example, in 2015, feedlot cattle DE was estimated at 82.5, and a Ym value predicted at 3.9%. The methods used to estimate DE and Ym for other types of cattle in the USA differ from the methods summarized here, and are described in the annexes to USA NIR 2017.

Further resources:

USA NIR 2017
Galyean and Gleghorn (2001) Summary of the 2000 Texas Tech University Consulting Nutritionist Survey. Texas Tech University. https://www.depts.ttu.edu/afs/burnett_center/progress_reports/bc12.pdf
Kebreab, E., Johnson, K.A., Archibeque, S.L., Pape, D. and Wirth, T., 2008. Model for estimating enteric methane emissions from United States dairy and feedlot cattle1. *Journal of animal science*, *86*(10), pp.2738-2748.
Vasconcelos and Galyean (2007) Nutritional recommendations of feedlot consulting nutritionists: The 2007 Texas Tech University Study. J. Anim. Sci. 85:2772-2781.

Inventory practice: Assessing sources of uncertainty in the livestock inventory of the United Kingdom

Tags: Uncertainty analysis | Monte Carlo analysis | sensitivity analysis | Europe

What data needs were addressed? Identifying the key sources of uncertainty in the national inventory.
Why was the data needed? The UK adopted a Tier 2 approach for livestock in 2000. However, no analysis of the sources of uncertainty in the inventory had been undertaken. In 2010, the UK government agency responsible for inventory compilation funded a project aiming to provide fundamental improvements in the accuracy and resolution of the UK national inventory and the development of a more detailed reporting methodology. As part of this project, a study was undertaken to quantify the uncertainty in the emissions of N_2O and CH_4 from agriculture for the year 2010 and the baseline year (1990), and the uncertainty in the trend between these two years, and to identify the inputs that had the greatest effect on uncertainty in the total emissions. Because the UK inventory uses activity data separately provided by devolved administrations in England, Scotland, Wales and Northern Ireland, the analysis also identified regional contributions to inventory uncertainty.

Methods used: Monte Carlo analysis, sensitivity analysis

How was the data gap addressed? Milne et al. (2014) report the methods and results of uncertainty analysis of CH_4 and N_2O emissions in the UK national GHG inventory. To quantify and identify the sources of uncertainty, Monte Carlo analysis was used. This method was chosen because it is straightforward to use, and can account for dependencies between inputs. In Monte Carlo simulation, model inputs are treated as random variables and are described by a probability density function (PDF). The mean of the PDF describes the expected value of the input and the variance reflects the uncertainty. A value for each input is pseudo-randomly sampled from the PDFs and the model is run to produce an output value. This process is repeated thousands of times, resulting in a set of output values which form an empirical distribution that describes the uncertainty. Statistics such as the mean, variance and 95% confidence intervals 96 can be derived from this distribution.

If the inventory is to use more Tier 3 calculations that use data at a higher resolution, this can be time- and resource-intensive. Therefore, to identify the inputs that had the greatest effect on uncertainty, sensitivity analysis was used. The effect of reducing uncertainty in the key parameters was tested by reducing the standard deviation of the PDFs associated with each input parameter by 50% in turn.

Initially, there was limited empirical evidence on the magnitude and form of uncertainty for many input variables. The researchers made assumptions about the distribution of variables, often based on previous literature – in particular, a previous analysis conducted for Finland (Monni et al 2007) – or IPCC guidance. For example, expected values and standard errors for livestock population data were calculated from national survey data. Where standard errors were less than 25% of the mean, a normal distribution was assumed, otherwise a lognormal distribution was used. For the uncertainty of input parameters to the IPCC Tier 2 enteric fermentation model various sources were used to estimate the standard errors and form of PDF (Table 1).

Table 1: References used for uncertainty estimates in Monte Carlo analysis

Parameter	Source of uncertainty estimate
Cfi, Ca, C, Cpregnancy, milk fat content, animal weight, digestible energy	Monni et al. (2007)
Feed energy density	McDonald et al (1981)
Milk yield	Farm business survey

Milne et al (2014)

Summarizing the main results for livestock methane emissions, the study found that:

- the inputs that most affected the uncertainty in CH_4 emissions were similar across the UK's constituent countries, although the order of importance varied slightly from country to country. In Wales and Scotland the emission factor for enteric fermentation from adult sheep had the largest impact on uncertainty, whereas in England and Northern Ireland model inputs for cattle emissions were more important.

- The most important inputs are: emission factors for enteric fermentation for dairy replacements, adult sheep, beef (other > 1year) and beef calves; the maintenance parameter for lactating cattle (Cfi); and feed digestibility for both beef and dairy cows.
- Reducing the uncertainty in the emission factor for enteric fermentation in dairy replacements in England by halving the standard deviation in its associated PDF resulted in a reduction in the standard deviation of modelled CH_4 from England of 10% in 1990 and 14% in 2010. The same reduction in the uncertainty for the emission factor for enteric fermentation in adult sheep in England (i.e. 50%) resulted in a 7% reduction in the standard deviation of the modelled emissions CH_4 from England in both 1990 and 2010.
- Literature values for uncertainty of model inputs were used for many parameters, so future uncertainty analysis could be improved by using country-specific estimates of uncertainty.

Further resources:

UK NIR 2017

McDonald, P., Edwards, R.A. and Greenhalgh, J.F.D. 1981. Animal Nutrition, 3rd Edition, Longman, London and New York

Milne, A.E., Glendining, M.J., Bellamy, P., Misselbrook, T., Gilhespy, S., Casado, M.R., Hulin, A., Van Oijen, M. and Whitmore, A.P., 2014. Analysis of uncertainties in the estimates of nitrous oxide and methane emissions in the UK's greenhouse gas inventory for agriculture. *Atmospheric environment*, *82*, pp.94-105.

Monni, S., Perälä, P. and Regina, K., 2007. Uncertainty in agricultural CH 4 and N 2 O emissions from Finland–possibilities to increase accuracy in emission estimates. *Mitigation and adaptation strategies for global change*, *12*(4), pp.545-571.

Inventory practice: Assessing sources of uncertainty in Finland's livestock inventory

Tags: Uncertainty analysis | Monte Carlo analysis| sensitivity analysis |Europe

What data needs were addressed? Identifying the key sources of uncertainty in the national inventory.

Why was the data needed? Finland began reporting cattle emissions using a Tier 2 approach in the 1990s, but Tier 1 was used for other livestock. Uncertainty analysis was used to identify emission sources and parameters in the Tier 2 model for which improved estimation methods could reduce overall uncertainty of the inventory.

Methods used: Monte Carlo analysis, sensitivity analysis

How was the data gap addressed? In the early 2000's, Finnish researchers applied uncertainty analysis to the national inventory in order to identify emission sources to target for improved estimation. The analysis, reported in Monni et al. (2007), used Monte Carlo analysis. The uncertainty of activity data was estimated by examining the data for representativeness and possible bias, informed by interviews with relevant experts. For example, cattle have individual ear marks that enable very accurate assessment of animal numbers (uncertainty of ±3%), but uncertainty in animal numbers for other species on farms is higher (±5%). For animal weight, the researchers divided the standard deviation of the total population by the square root of the number of animals in each category to obtain a standard deviation of the mean value. Additional uncertainty was added, based on expert judgement, to reflect the effects of estimating animal weights using heart girth measurements. The distribution of data for each parameter was established following IPCC guidelines, i.e. assume normal distribution for empirical data unless other distributions fit the data better. Monte Carlo simulation was used to combine uncertainties, and sensitivity analysis was used to identify the most important factors affecting uncertainty. The analysis identified higher uncertainty of emission factors for bulls, heifers and calves than for dairy cattle, mostly affected by digestibility and net energy for maintenance. It concluded that using a Tier 2 approach for all animal types would reduce uncertainty in the agriculture inventory by 3%.

Further resources:

Finland NIR 2017

Monni, S., Perälä, P. and Regina, K., 2007. Uncertainty in agricultural CH 4 and N 2 O emissions from Finland–possibilities to increase accuracy in emission estimates. *Mitigation and adaptation strategies for global change*, *12*(4), pp.545-571.

Inventory practice: Prioritization of key categories in the United Kingdom's inventory

Tags: Key category analysis | ranking and scoring | Europe

What data needs were addressed? To prioritize which inventory key categories should be the focus for improvement.

Why was the data needed? The UK's inventory applies Approaches 1 and 2 to key category analysis. In the latest inventory, 39 inventory categories are identified as key categories. With limited resources for inventory improvement, a method was needed to help prioritize key categories.

Methods used: Ranking and scoring

How was the data gap addressed? The UK has developed a ranking system to prioritize key categories. The Key Category Analysis (KCA) ranking system works by allocating a score based on how high categories rank in the base year and most recent year level assessments and the trend assessment for the Approach 1 KCA including LULUCF. For example, in the base year (1990) level assessment, enteric fermentation from cattle was the 10th largest emission source; the 7th largest in the most recent (2018) level assessment; and ranked 14th in the most recent trend assessment. This category is therefore given a score of 10+7+14=22. The categories are then ranked from lowest score to highest, with scores that are equal resolved by the most recent year level assessment. In the 2018 KCA ranking results, enteric fermentation from cattle was ranked 9th out of all key categories.

The assessments used in this ranking exercise are only those *including* LULUCF, because if the additional *excluding* LULUCF assessments were also used, the LULUCF sectors would only be included in half of the assessments and would therefore give an unrepresentative weighting.

Further resources:
UK NIR 2018
IPCC 2006 Volume 1 Chapter 4

Inventory practice: Characterization of dairy cattle

Tags: Livestock characterization | dairy cattle | Asia | Europe | Africa | Oceania

Enteric fermentation and manure management emissions from dairy cattle are a key category in many countries' national GHG inventories. Countries have developed different methods of categorizing dairy cattle. The following provide examples of different categorization methods.

One category (mature dairy cows only): Until 2018, the UK's national inventory categorized only 1 cattle sub-type as 'dairy cows'. Animal population data come from the annual agricultural survey. This survey collects data on the 'dairy breeding herd', which is defined as dairy cows over two years of age with offspring. Dairy heifers, dairy replacements > 1 year, and dairy calves < 1 year are included along with beef heifers and beef calves in the category 'other cattle'. Dairy cow emissions were estimated using a Tier 2 approach, while emissions from 'other cattle' used a Tier 1 approach.

Sub-categories based on age, sex and physiological status:

- Japan's inventory applies a Tier 2 approach to all sub-categories of cattle. Dairy cattle are divided into lactating and non-lactating cows, and heifers. Calves of dairy breeds are included in the 'non-dairy cattle' category.
- South Africa's inventory, based on research by Du Toit et al (2013) categorizes dairy cattle by age, physiological status and production system (Table 1).

Table 1: Enteric fermentation emission factors of dairy cattle sub-categories in South Africa's inventory

	Total mixed ration based production system	Pasture-based production system
	Emission factor ($kgCH_4$/head/year)	Emission factor ($kgCH_4$/head/year)
Lactating cows	132	127
Lactating heifers	127	116
Dry cows	80.4	83.4
Pregnant heifers	67.7	61.8
Heifers >1 year	62.6	52.6
Heifers 6-12 months	42.1	37.1
Heifers 2-6 months	22.5	24.5
Calves	21.5	20.0

Source: Du Toit et al (2013)

Sub-categories by region: New Zealand's agricultural statistics report numbers of dairy cows and heifers in milk or calf, non-milking cows, heifers, yearlings and bulls, and calves born alive in each year. Before 2010, the inventory estimated emissions for each sub-type of dairy cattle at the national level. An assessment found that because development dairy cattle population numbers and productivity had been uneven across the country, using a single national approach was no longer the most accurate way of estimating dairy cattle emissions. A time series of data on dairy cattle populations, live weight, milk yield and milk fat and protein contents was available at regional level. Since 2010, the national inventory separately estimates emissions from different sub-types of dairy cattle in 17 regions, which are then aggregated to the national level.

Further resources:

UK NIR 2017
Japan NIR 2017
Clark H (2008) A comparison of greenhouse gas emissions from the New Zealand dairy sector calculated using either a national or regional approach. Available at https://www.mpi.govt.nz/dmsdocument/2936/loggedIn
Du Toit, C.J.L. and Van Niekerk, W.A., 2013. Direct methane and nitrous oxide emissions of South African dairy and beef cattle. *South African Journal of Animal Science*, *43*(3), pp.320-339.

Inventory practice: Livestock characterization in Uruguay

Tags: Livestock characterization | cattle| South America

What data needs were addressed? Categorizing livestock to reflect both differences in production systems in the country and data availability.

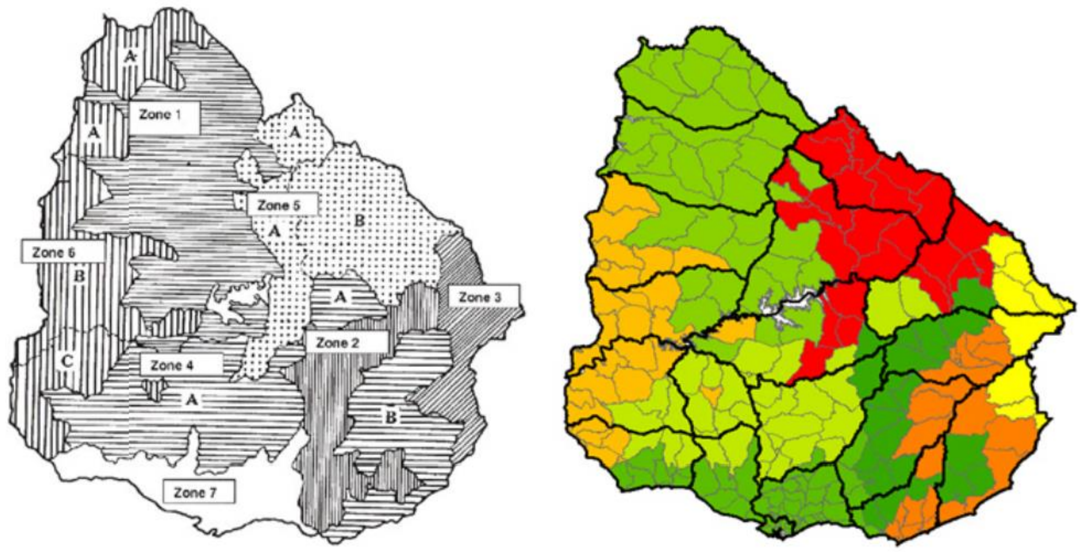
Why was the data needed? Beef production is a major part of Uruguay's economy, an important source of export earnings, and the source of about 40% of total national GHG emissions. Uruguay's NDC has set a domestic target of reducing GHG emissions per kilo of beef by 33% in 2030 compared to 1990 levels. A Tier 2 approach is essential for tracking change in emissions and emission intensity. The 2004 national inventory had divided the country into four regions based on administrative territories. A review of the inventory identified the need to adopt a Tier 2 approach, for which an appropriate characterization of livestock was needed.

Methods used: Livestock characterization

How was the data gap addressed? When the Climate Change Unit of the Ministry of Housing, Territorial Planning and Environment first began to develop a Tier 2 approach, a group of experts was convened to develop an improved regional characterization of livestock and livestock sub-categories. The working group of experts consisted of representatives from the Climate Change Unit, the Ministry of Livestock, Agriculture and Fisheries, agricultural research institutes and universities, industry bodies and private sector experts.

Based on national research on agro-ecological zones, the country was divided into 7 zones, defined by soil types, the type and quality of the pastures, and the dominant production systems. The cattle population was divided into 9 sub-categories: bulls, breeding cows, wintering cows, bulls >3 years old, steers 2-3 years, bulls 1-2 years, heifers > 2 years, heifers 1-2 years old, and calves. Within each of the 7 zones, data on the livestock population was obtained at the administrative level of Police Sections, an administrative division, on average 7000 hectares in size, that is the spatial basis for collection of agricultural statistics. Information on the production and feeding systems, and animal performance was obtained for each of the 7 zones from national publications or expert judgement from the group of experts.

Figure 1: Division of Uruguay's national territory by agro-ecological zone (left panel) and by combination of agroecological zone and administrative regions (right panel)



Source: Uruguay BUR1

Further resources:
Uruguay BUR 1 https://unfccc.int/sites/default/files/URUBUR1.pdf

GRA and CCAFS (n.d.) Livestock development and climate change: the benefits of advanced greenhouse gas inventories. https://globalresearchalliance.org/wp-content/uploads/2018/02/Benefits-of-Greenhouse-Gas-Inventories-Aug-2016.pdf

Inventory practice: Regional characterization of dairy cattle in New Zealand

Tags: Livestock characterization | dairy cattle| Oceania

What data needs were addressed? Regional characterization of dairy cattle.

Why was the data needed? New Zealand's initial Tier 2 approach allocated the livestock population to 3 different types of grassland (i.e. improved, unimproved and tussock) in 4 climate zones. Later analysis suggested that allocating all animals to 1 climate region and 1 of grassland changed total methane emissions by around 1% (Clark 2001). So when a revised Tier 2 approach was adopted in 2002, detailed spatial categorization was no longer used. To account for differences in dry matter intake and methane conversion rates (Ym), weighted averages based on the proportion of animals in each pasture type were used. However, by the second half of the 2000s, the dairy sector had undergone rapid change, with large increases in the dairy population and productivity in some regions. This meant that a single national model for dairy emissions may no longer be accurate.

Methods used: Regional characterization of dairy cattle

How was the data need addressed? A study (Clark 2008) was undertaken to compare the differences in dairy cattle emissions estimated using a single national model and an aggregation of regional models. The study identified data on dairy cattle populations and animal performance that were both available at the regional level. Official population data were available for 73 Local Territory Authorities, while the animal performance data (i.e. total milk produced, milk fat and protein content, weight of dairy cows by breed and proportion of each breed in the national herd) were available from a farmer cooperative disaggregated into 17 regions. Both data sources provided time series going back to 1990. These data sources were already used in the national inventory. Therefore, the comparison was a test of whether the national GHG emissions model was linear or not: if it was linear, national and aggregated regional estimates would be identical.

The results showed that for 1990, the two models yielded very similar results. However, for 2006, differences were more significant, with the regional model estimating 2.3% lower national dairy cattle emissions than the national model. The trend in emissions is therefore non-linear. The reason is that emissions are most directly related to feed consumption, but feed consumption is estimated on the basis of animal performance (e.g. milk yield, live weight), which is not linearly related to feed consumption. That is, each additional unit of milk requires a smaller percent increase in feed intake, because maintenance requirements have already been met.

Using the results of this study, the national inventory adopted a regional model for estimating dairy emissions. Emissions from other livestock types are still produced using a single national model because regional data is not available.

Table 1: Comparison of dairy cattle emission estimates made using a single national model and an aggregation of 17 regional models.

	Enteric fermentation (Gg)		CH_4 manure management (Gg)		N_2O manure management (Gg)	
	1990	2006	1990	2006	1990	2006
National model	232.90	413.30	9.70	17.69	7.48	13.02
Aggregated regional model	232.18	404.71	9.68	17.38	7.34	12.64

Difference	-0.72	-8.59	-0.02	-0.32	-0.10	-0.38

Further resources:

Clark H (2001). Ruminant methane emissions: a review of the methodology used for national inventory estimations. A report prepared for the Ministry of Agriculture and Forestry.

Clark H (2008). A comparison of greenhouse gas emissions from the New Zealand dairy sector calculated using either a national or a regional approach. https://www.mpi.govt.nz/dmsdocument/2936-a-comparison-of-greenhouse-gas-emissions-from-the-new-zealand-dairy-sector-calculated-using-either-a-national-or-a-regional-approach

Inventory practice: Structured elicitation of expert judgement in Canada's initial Tier 2 inventory

Tags: Expert judgement | surveys| milk yield | animal weight | weight gain | North America

What data needs were addressed? Information on management practices and performance of cattle.

Why was the data needed? When Canada first adopted a Tier 2 approach, various sources of information on cattle production practices and performance were used. Initially, data from surveys published in scientific journals was used, but this was not available for all animal sub-types.

Methods used: Surveys of regional experts.

How was the data need addressed? Surveys posing questions on dairy and beef production practices were administered to about 100 cattle specialists at the regional and/or provincial level in the country, with fewer (e.g. 6) specialists contacted in provinces with smaller cattle populations and more (e.g. 15) contacted in provinces with larger populations. The survey asked the specialists to provide estimates for key parameters (e.g. average weight, mature weight, weight gain and weight loss during lactation, milk yields, conception rates) and to describe key production practices (e.g. time spent in confinement and on pasture in a year, type of feed fed (type of grain and hay/silage fed) and % of grain in the diet).

The data from the surveys were then collated in a table together with existing published data and other data sources (e.g. personal communications from experts on particular topics). Examples selected from the collated results of the survey are given in Table 1. In this way, the survey data were used to fill data gaps in the inventory. For example:

- Milk yield and milk fat data: records of milk yield were available for 8 provinces. For 2 provinces with no recorded data, survey data were used.
- Animal weight and weight loss: Survey data on weight loss were used for 2 provinces where no other data source was available.
- Production practices (e.g. housing, grazing, feed) were estimated based on the predominant practice in each province.

Table 1: Collation of structured survey data and literature values for dairy cows in one Canadian province (values with no given source are from the survey)

	Dairy cows
Average weight (kg)	700
Mature weight (kg)	700
Daily weight gain (kg/d)	0.7 (young stock), 0.3 (cows)
Weight loss (kg/d)	-1.28 for first 70 days of lactation
Milk (kg/d)	33.0 31.9 (recorded data)

Milk fat (%)	3.5 3.6 (recorded data)
Conception rate (%)	55 (first service) 67 (Usenik, pers. comm.. with first service based on only 30% of population)
Days in milk (d)	351 (survey estimate) 351 (recorded)
Days dry (d)	75 (survey estimate) 75 (recorded)
Production environment	95% confinement housing, dry cows in dry pens for 7-8 weeks, and 1 week in calving pen
Feed	TMR (60% forage, 40% concentrate) for 351 days

The survey results were compiled in an internal report, a summary of which was published in Ominksi et al (2007), and results were incorporated into Canada's national inventory (2005).

Further resources:

D. Boadi, K. H. Ominski, D.L. Fulawka and K. M. Wittenberg (2004) Improving Estimates of Methane Emissions Associated with Enteric Fermentation of Cattle in Canada by Adopting an IPCC (Intergovernmental Panel on Climate Change) Tier-2 Methodology. K2362-3-0088. Unpublished report

Canada NIR 2005

Ominski, K.H., Boadi, D.A., Wittenberg, K.M., Fulawka, D.L. and Basarab, J.A., 2007. Estimates of enteric methane emissions from cattle in Canada using the IPCC Tier-2 methodology. *Canadian journal of animal science*, *87*(3), pp.459-467.

Inventory practice: Estimating livestock population time series in Romania

Tags: Livestock population | extrapolation | expert judgement | cattle| Europe

What data needs were addressed? To construct a time series for livestock populations.

Why was the data needed? Prior to 2012, Romania used a Tier 1 approach for all livestock types. National primary data on the total number of cattle was sufficient for a Tier 1 approach. When a Tier 2 approach was adopted, a time series for the population of cattle sub-categories was needed, but official data did not report cattle sub-categories until 2004.

Methods used: extrapolation, expert judgement, comparison with FAO and EUROSTAT databases

How was the data need addressed? An institute was contracted to produce a time series for the population of cattle sub-categories. Based on their proportions in the 2004 data, for 1989-2003, the following proportions of sub-categories in the total cattle population were assumed:

- Dairy cattle are 56% of the total cattle population

Among non-dairy cattle,

- calves for slaughter < 1 year old represent 10.03% of total cattle;
- young cattle for breeding < 1 year old represent 15.3% of total cattle;
- young cattle for breeding between 1-2 years represent 7.97% of total cattle
- *male cattle >2 years* 0.34%
- *female cattle >2 years* 5.83%
- males and females > 2 years for slaughter 1%
- cattle for work 1.94%.

Assuming a constant herd structure was in line with expert opinion that herd structure did not change significantly over this period. Since 2004, primary data on all sub-categories have been collected by the

National Institute of Statistics (NIS). The data are published in the Statistical Yearbook of Romania and reported by NIS to EUROSTAT, which also publishes the data.

In 2015, the primary livestock population time series were verified by comparing the data in the inventory with data published by FAO and EUROSTAT. It was found that EUROSTAT data round livestock populations to the nearest hundred, causing small errors in the time series. Differences with FAO data were due to the fact that the values for the year X are allocated by FAO of year X-1, and to rounding.

Further resources:
Romania NIR 2017
FAOSTAT

Inventory practice: Livestock population estimates in Croatia

Tags: Livestock population | extrapolation | expert judgement | cattle| Europe

What data needs were addressed? To construct a time series for livestock populations.

Why was the data needed? Croatia has used a Tier 2 approach for cattle emissions since 2009. Cattle are categorized as mature dairy cows, mature non-dairy animals and calves. The challenges were to reconstruct time series for each of the cattle sub-categories when national official statistics were not available for all years, and the sub-categorizations in national statistics changed over time.

Methods used: extrapolation, expert judgement

How was the data need addressed? The Croatian Bureau of Statistics (CBS) holds data on other cattle since 1990. Numbers of dairy cattle were provided by the Croatian Agricultural Agency (CAA) for the years 2008-2015. For 1990 to 2007, dairy cattle numbers were extrapolated based on the 2008-2015 numbers using expert opinion from the Croatian Agency for the Environment and Nature. For non-dairy cattle, the sub-categories reported by the CBS has changed over time. The table below shows how different categories were mapped onto the IPCC categories over time.

Table 1: Changing classifications of non-dairy cattle in Croatia

IPPC categories	CBS categories		
	1990-1999	2000-2006	2007-2015
Mature non-dairy cattle	▪ Heifers ▪ Other cows ▪ Other (bull, ox)	▪ Other cows ▪ Other (bull, ox) ▪ Pregnant heifers ▪ Calves over 2 years old	▪ Heifers over 2 years old ▪ Cows (female bovine animals that have calved) ▪ Other bovine animals over 2 years old
Young cattle	▪ Bovine animals aged under 2 years	▪ Calves under 3 months ▪ Calves 3 month – 1 year of age ▪ Calves 1-2 years of age	▪ Bovine animals less than 1 year old (includes calves for slaughter and other young male and female) ▪ Bovine animals aged between 1 and 2 years (male and female animals for slaughter and breeding)

Further resources:
IPCC (2006) Ch 10
Croatia NIR 2017

Inventory practice: Characterization of manure management systems in Finland

Tags: manure management | surveys | interpolation | cattle | Europe

What data needs were addressed? To quantify the allocation of manure among different manure management systems.

Why was the data needed? The Finnish government does not collect data on manure management systems in a format suitable for use in the inventory. Prior to 2014, Finland's inventory used expert judgement applied to limited data from a government survey to characterize the allocation of manure to different management systems. An improved estimate was needed.

Methods used: farm survey, interpolation

How was the data need addressed? As part of a study funded by the environment agency to identify ways to reduce ammonia emissions, a new questionnaire was made and sent to more than 11,000 farms, of which approximately 23% replied. Based on the data collected, activity data on the shares of manure management systems for 1990 to 2005 were kept the same as before (except for dairy) but from 2006 onwards the values were updated. The 2012 management system data was updated and data for years between 2006 and 2011 were interpolated. The values from 2013 onwards are based on an estimated trend between 2012 and 2020 that assumes the share of slurry will continue to increase.

It is planned in the future to improve data on the share of manure in dry lots, which are currently estimated at about 1-3% of excreted manure.

Further resources:
Finland NIR 2017
Grönroos, J (2014). Reduction possibilities and costs of agricultural ammonia emissions. Available at: https://helda.helsinki.fi/handle/10138/152766 (in Finnish)

Inventory practice: Estimating number of days alive

Tags: Livestock population | surveys | interpolation | expert judgement | cattle | pigs | poultry | Europe | North America | Africa

IPCC Guidance suggests that the livestock population data used should be the annual average population:

Annual average population = days_alive * (number of animals produced annually / 365)

Many countries do not report in detail how the number of days alive is estimated for cattle, focusing mainly on the gradual growth of cattle populations over time. For beef finishing cattle, swine and poultry, however, estimation of days alive is more common. Countries use various methods to estimate the annual average population and number of days alive. Some examples include:

Modelling different production stages using expert judgement: Canada's inventory uses cattle subcategory population data from national statistics (e.g. cows, heifers, steers etc). Each sub-category is then divided into production stages (e.g. background heifers and steers, finishing heifers and steers, short- and long-finish feedlot heifers and steers). The proportion of each subcategory backgrounded or on feedlot, and the duration on feedlots until marketing were estimated using expert judgement elicited through a nationwide survey of livestock experts (see Inventory Practice: Structured elicitation of expert judgement in Canada's initial Tier 2 inventory). The inventory estimates GE and CH_4 emissions per subcategory of animal, considering also the number of days spent in each production stage.

Expert judgement: Croatia's Tier 2 inventory uses expert judgement from the Faculty of Agriculture at the University of Zagreb estimate the number of days alive for swine and poultry:

Table 1 Livestock categories and days alive estimated to calculate annual average population in Croatia

Disagregated livestock categories	Days alive	Disagregated Livestock categories	Days alive
Market swine (nursery, finishers, fattening pigs)		**Poultry**	
0-20 kg	70 days	Layers	365 days
20-50 kg	112 days	Broilers	51 days
50-80 kg	160 days	Turkeys	240 days
80-110 kg	202 days	Geese	180 days
110+ kg	365 days	Ducks	180 days
		Other	365 days

Source: Croatia NIR 2017

Similarly, South Africa's inventory uses research that assumed feedlot cattle are kept on the feedlot for 110 days (i.e. assuming 3 cycles per year).

Many countries also adjust emission factors for calves before weaning, and consider that enteric fermentation emissions are significant only after weaning. The duration of suckling is mostly determined by expert judgement.

Further resources:

Canada NIR 2017

Croatia NIR 2017

Du Toit, C.J.L. and Van Niekerk, W.A., 2013. Direct methane and nitrous oxide emissions of South African dairy and beef cattle. *South African Journal of Animal Science*, *43*(3), pp.320-339.

Inventory practice: Structured elicitation of expert judgement on manure management systems in Canada

Tags: manure management | surveys | expert judgement | cattle | North America

What data needs were addressed? Information on manure management practices.

Why was the data needed? In Canada's initial inventories in the 1990s, the distribution of manure management practices was estimated using expert judgement by a small number of experts. Some government data was available, but only for a small number of manure management systems and a few livestock types. Improved estimates reflecting the diversity of practices across the country were needed.

Methods used: Surveys of regional experts.

How was the data need addressed? Before designing the survey was designed, it was necessary to define the major manure management practices in the country so that the survey is in line with IPCC definitions of manure management systems as well as reflecting national conditions. This was done by the contracted researcher in collaboration with two manure experts. The survey was then designed and sent to 68 experts in different provinces, including government staff as well as private sector waste management experts. Responses were received from 16 experts. The survey tool asked each person to read the definitions of manure management systems and to indicate the percentage of manure in each system for each type of livestock in their province. Where more than one response was received from the same province, the average value was taken. The survey results were then compared to the existing limited government data, which confirmed the dominant patterns of manure storage methods reflected in the government survey. Table 1 shows the summary results for beef cattle in different provinces.

Table 1: Percent distribution of manure management practices by province for beef cattle

	B.C.	AB	SK	MB	ON	QC[1]	NB	PE	NS[2]	NL
Pasture/Range/Paddock	***70***	***45***	***48***	***70***	***33***	***50***	***50***	***40***	***49***	***N/A***
Solid	***29***	***48***	***50***	***30***	***64***	***40***	***45***	***60***	***44***	***N/A***
Feedlot	25	48	30	--	32	20	14	30	5	--
Loose housing with bedded pack	4		20	--	32	18	31	30	32	--
Manure cleaned to an outdoor pile	--	--	--	--	--	2	--	--	7	--
Liquid	***0***	***0***	***0***	***0***	***3***	***10***	***5***	***0***	***7***	***N/A***
Storage tank beneath barn	--	--	--	--	3	--	--	--	3	--
Outdoor concrete/steel tank	--	--	--	--	--	--	--	--	3	--
Outdoor earthen storage tank	--	--	--	--	--	--	--	--	1	--
Other	***1***	***7***	***2***	***0***	***0***	***0***	***0***	***0***	***0***	***N/A***
Anaerobic digester	--	2	--	--	--	--	--	--	--	--
Composting system	1	5	2	--	--	--	--	--	--	--

Source: Marinier et al. 2004.

Since production systems have not changed significantly, Canada's inventory continues to use this distribution of manure management practices, combined with annual data on the population of livestock in each province, which changes from year to year. However, academic studies have pointed to some ways in which Canada's manure management emission estimates could be improved (Vanderzaag et al. 2013).

Further resources:

Canada NIR 2017

Marinier, M., Clark, K. and Wagner-Riddle, C., 2004. *Determining manure management practices for major domestic animals in Canada*. Environment Canada, unpublished report.

VanderZaag, A.C., MacDonald, J.D., Evans, L., Vergé, X.P.C. and Desjardins, R.L., 2013. Towards an inventory of methane emissions from manure management that is responsive to changes on Canadian farms. *Environmental Research Letters*, *8*(3), p.035008.

Inventory practice: QA/QC in Poland's GHG inventory

Tags: QA/QC | institutional arrangements | Europe

Poland's inventory compilation agency, National Centre for Emission Balancing and Management (KOBiZE), has put in place a **quality assurance (QA), quality control (QC)** and verification programme for the annual GHG inventory.

QC activities are carried out by the personnel directly responsible for the inventory and are aimed at maintaining standards and quality. The main QA activities conducted are Tier 1 methods applied to all sources and sinks. Tier 2 procedures are applied to key categories (including enteric fermentation). QC covers routine technical activities to maintain the correctness and completeness of data and eliminate errors and determine potential deficiencies. Checks are made on the accuracy of data and the procedures for calculation of emissions, uncertainty, archiving of information and reporting.
QA covers procedural systems for control carried out by experts not involved directly in compiling the inventory in a given sector. QA activities are conducted on a completed inventory and aim to ensure that national inventory represents the best level of knowledge and available data, and to support QC.
Verification activities include comparisons with external emission analyses estimates and databases prepared by independent bodies or teams. They allow to improve inventory methods and outcomes in both the short and long term.
The KOBiZE **Data Management Manual describes the inventory requirements for** databases, software, worksheets, final reports as well as QA/QC documentation. Documentation of data and calculation QC are archived in electronic and hardcopy forms. The main procedures for QA/QC activities are described in the *National Quality Assurance / Quality Control and Verification Programme of the Polish Greenhouse Gas Inventory* and the detailed QC procedures are procedures performed by KOBiZE experts.

Table 1 summarizes the timeframe for inventory compilation and QA/QC activities. The dates for particular stages are established based on country specific availability of statistical data as well as national (legal) and international obligations.
Table 1: Timetables for inventory preparation and check (n-submission year) in Poland

Timing	Activity
June – 15 December (year n-1)	• Data and emission factor collection (estimation) • Check for consistency and correctness of emission data, trends and factors, using QC and verification methods • Initial calculations and checks of GHG emissions • Submission to Ministry of Environment for acceptance
15 January (year n-2)	• Submission of GHG inventory for the year n-2 and elements of NIR to EIONET CDR as required by EU regulations
15 December – 15 February (year n-2)	• Emission results and methodology verification based on comments from ministerial emission experts (QA methods applied) • Elaborate final inventory, additional checks and final corrections, preparation of NIR and CRF tables (QC and verification methods applied) • Submission to Ministry of Environment for acceptance
15 March (year n-2)	• Emission results and methodology verification based on comments by external sector experts in inter-ministerial check of the report (QA methods applied) • Submission of NIR and CRF tables to EIONET CDR as required by EU regulations
15 April (year n-2)	• Submission of GHG inventory for the year n-2 to UNFCCC secretariat (NIR and CRF tables)

Source: Poland NIR 2017

Each inventory sector undergoes detailed QC procedures carried out by a designated expert during its preparation, after completing the calculations, after generating the CRF tables generation and after completing the NIR report.

As a part of QA activity, the inventory team cooperates with specialists from different institutes, associations and individual experts who are involved in verification of data and assumptions to the inventory. Domestically, once the NIR is delivered to the Ministry of Environment, it undergoes internal consultation among departments, and external consultation through inter-ministerial dialogue, during which agencies sub-ordinate to the relevant ministry review the inventory. QA is also performed by EU and UNFCCC agencies.

After including obtained comments and amendments into the NIR, the NIR is sent to the European Commission where inventory results and methodology are also discussed. The national inventory results are also verified by the European Union. Since 2012 this verification is performed using the *EEA Emission Review Tool (EMRT, https://emrt-esd.eionet.europa.eu/eea-review-tool)*.

The results of the submitted CRF files are also controlled by the UNFCCC Secretariat, and annual international review of the Polish GHG inventory under UNFCCC is a key element in the process of quality improvement.

Further resources:
Poland NIR 2017

Inventory practice: QA/QC in Norway‘s GHG inventory

Tags: QA/QC | Europe

Norway’s inventory uses a range of methods to ensure quality assurance (QA) and quality control (QC). These include:

Check that assumptions and criteria for the selection of activity data and emissions factors are Documented: Thorough checks of emission factors and activity data and their documentation are performed for all emission sources.
Check for transcription errors in data input and references: Activity data are often statistical data. Official statistical data undergo a systematic revision process, which may be manual or, increasingly frequently, computerised. The revision significantly reduces the number of errors in the statistics used as input to the inventory. All input data (reported emissions, emission factors and activity data) for the latest inventory year are routinely compared to those of the previous inventory year, using automated procedures. Large changes are automatically flagged for further, manual QC.
Check that emissions are calculated correctly: When possible, estimates based on different methodologies are compared.
Check that parameter and emission units are correctly recorded and that appropriate conversion factors are used: All parameter values are compared with values used in previous years and with any preliminary figures available. Whenever large deviations are detected, the value of the parameter in question is first checked for typing errors or unit errors. If necessary, the primary data suppliers are contacted for explanations and possible corrections.
Check the integrity of database files: Control checks of whether appropriate data processing steps and data relationships are correctly represented are made for each step of the process. It is verified that data fields are properly labelled, have correct design specifications and that adequate documentation of database and model structure and operation are archived.
Check for consistency in data between source categories: Activity data and other parameters that are common to several source categories should be evaluated for consistency, e.g. activity data used for enteric fermentation, methane and nitrous oxide manure management emissions.
Check that the movement for inventory data among processing steps is correct: Statistics Norway has established automated procedures to check that inventory data fed into the model does not deviate too much from the estimates for earlier years, and that the calculations within the model are correctly made. Checks are also made that emissions data are correctly transcribed between

different intermediate products. The model is constructed so that it gives error messages if factors are lacking, which makes it quite robust to miscalculations.
Undertake review of internal documentation: For some sources, expert judgements dating some years back are used with regard to activity data/emission factors. In most of the cases these judgements have not been reviewed since then, and may not be properly documented, which may be a weakness of the inventory. The procedures have improved the last few years, and the requirements for internal documentation to support estimates are now quite strict; all expert judgements and assumptions made by the Statistics Norway staff should be documented.
Check of changes due to recalculations: Emission time series are recalculated every year to ensure time series consistency. The recalculated emission data for a year are compared with the corresponding estimates from the year before.
Undertake completeness checks: Estimates are reported for all source categories and for all years to the best of our knowledge. During the implementation of the 2006 IPCC Guidelines, a systematic evaluation of all potential new sources was performed.
Compare estimates to previous estimates: Internal checks of time series for all emission sources are performed every year when an emission calculation for a new year is implemented. It is examined whether any detected inconsistencies are due to data and/or methodology changes.

Further resources:
Norway NIR 2017

Inventory practice: Quality assurance and quality control in The Netherlands

Tags: QA/QC | institutional arrangements | Europe

What data needs were addressed? Documentation of methodologies employed as part of The Netherlands' inventory.

Why was the data needed? To implement quality control of data, calculations and resulting emissions, and to document updates to methodologies employed in the country's national inventory.

Methods used: Structured quality assurance and control procedures, documentation in methodology reports.

How was the data need addressed? The Pollutant Release and Transfer Register group, a collaborative group including Statistics Netherlands (CBS), Wageningen University & Research centre (WUR), the National Institute for Public Health and the Environment (RIVM), and PBL Netherlands Environmental Assessment Agency (PBL), is responsible for the collection and establishment of yearly emissions of pollutants to air, water and soil in the Netherlands. The group has a task force leader Agriculture responsible for quality assurance and quality control.

Every year, a check is done on (a) documentation and adoption of data, (b) correct implementation of calculations, (c) consistent use of assumptions and specific parameters and (d) application of complete and consistent datasets. As a result, an action list is developed, listing any actions relevant as a result of the quality control. The list is shared with the secretary of the Emission Registration group.

Furthermore, every year a trend analysis is done, comparing new data with data from the previous year. If emissions exceed 5% at target group or 0.5% at national level, an explanation is sought and again communication to the secretary of the Emission Registration group.

A logbook of all quality control checks, results, explanations and actions is kept at the Emission Registration secretary. Based on the results of the trend analysis, feedback on the control and correction process ('action list') the Working Group on Emissions Monitoring (WEM) gives advice to the institute representatives (Deltares on behalf of Rijkswaterstaat, Statistics Netherlands (CBS) and Netherlands Environmental Assessment Agency (PBL)) to approve the dataset.

Detailed methodologies employed as well as any updates of methodologies are reported in separate methodology reports.

Further resources:

Vonk, J., S.M. van der Sluis, A. Bannink, C. van Bruggen, C.M. Groenestein, J.F.M. Huijsmans, J.W.H. van der Kolk, L.A. Lagerwerf, H.H. Luesink, S.V. Oude Voshaar & G.L. Velthof (2018). Methodology for estimating emissions from agriculture in the Netherlands – update 2018. Calculations of CH4, NH3, N2O, NOx, PM10, PM2.5 and CO2 with the National Emission Model for Agriculture (NEMA). Wageningen, The Statutory Research Tasks Unit for Nature and the Environment (WOT Natuur & Milieu). WOt-technical report xxx. xxx p; 54 Tab.; 2 Fig.; 102 Ref.; 12 Annexes.

Vonk, J., A. Bannink, C. van Bruggen, C.M. Groenestein, J.F.M. Huijsmans, J.W.H. van der Kolk, H.H. Luesink, S.V. Oude Voshaar, S.M. van der Sluis & G.L. Velthof (2016). Methodology for estimating emissions from agriculture in the Netherlands. Calculations of CH4, NH3, N2O, NOx, PM10, PM2.5 and CO2 with the National Emission Model for Agriculture (NEMA). Wageningen, The Statutory Research Tasks Unit for Nature and the Environment (WOT Natuur & Milieu). WOt-technical report 53. 164 p; 21 Tab.; 1 Fig.; 108 Ref.; 12 Annexes.

Inventory practice: QA and verification in Australia's GHG inventory

Tags: QA/QC | Oceania

Australia has applied a variety of methods to review and verify the data, methods and results of its livestock inventory. NIR 2017 reports the following activities have been conducted:

Inventory element assessed	Methods for QA/QC or verification	Summary findings
Activity data	Australian Bureau of Statistics has QAQC procedures QAQC procedures applied in inventory compilation Inverse modelling of cattle and sheep populations to ensure consistency with reported populations External reviews of data	No apparent bias in sheep numbers, possible differences in cattle numbers were incorporated into uncertainty estimates
Implied emission factors	IEFs were compared with IPCC defaults for the region	Higher dairy cattle IEF can be explained by higher milk yield in Australia than in the IPCC default
Feed intake	Comparison of feed intake estimates with IPCC recommended 1-3% of live weight Comparison with feed or energy intake values in other countries' inventories	
Methane conversion rates	Comparison with IPCC values Reference to scientific reviews	Conversion rates consistent with IPCC default Inventory values within the range reported in the literature and supported by meta-analysis

Further resources:
Australia NIR 2017

Inventory practice: Verification of Denmark's inventory inputs and results

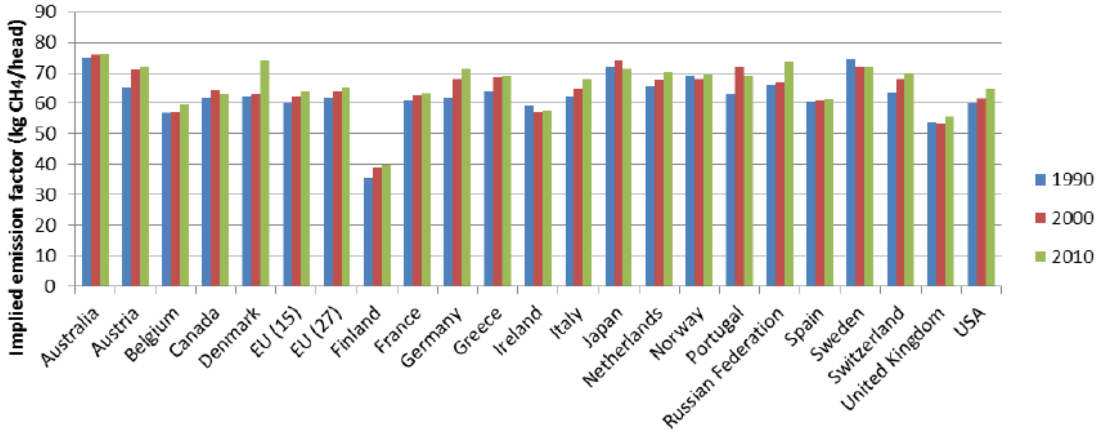
Tags: QA/QC | verification | Europe

The Danish GHG inventory is compiled annually by DCE, the Danish Centre for Environment and Energy at Aarhus University (AU), on behalf of the Danish Ministry of Environment. verification activities help establish the reliability of the GHG inventory and may help to point to potential quality improvements in specific sectors/categories. In 2013, an verification was commissioned and conducted by a team of experts from the Department of Environmental Science/DCE, Aarhus University with contribution from external reviewer Ricardo Fernandez, European Environment Agency (EEA). The verification focussed on 25 identified key categories covering energy, agriculture, industry and waste. Using inventory data for 1990 (base year), 2000 and 2010, comparisons of activity data and emission trends were made with data from other sources (e.g. EUROSTAT for agricultural statistics) and with emission factors and trends reported by other countries, such as other EU countries, Australia, Canada, Japan, Russian Federation and the USA.

For livestock data, the following were assessed:

- Activity data used in the inventory were compared with livestock population data reported by EUROSTAT. For cattle, for example, the deviation between the two sources was less than 4 %,
- Comparison of the implied emission factor not only showed that the IEF was in a similar range to other countries, but that the upward trend in the IEF was also seen in other countries' submissions (Figure 1).

Figure 1: Comparison of Denmark's IEF with IEFs reported by other countries



Source: Fauser et al. 2013

Similar analysis was conducted for other livestock types and other livestock-related emission sources, and analysis determined the reasons for any differences with other countries' inventory results.

Further resources:

Fauser, P., Nielsen, M., Winther, M., Plejdrup, M., Gyldenkærne, S., Mikkelsen, M.H., Albrektsen, R., Hoffmann, L., Thomsen, M., Hjelgaard, K. & Nielsen, O.-K. 2013. Verification of the Danish 1990, 2000 and 2010 emission inventory data. Aarhus University, DCE – Danish Centre for Environment and Energy, 85 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 79. http://dce2.au.dk/pub/SR79.pdf

Inventory practice: Sensitivity analysis to prioritize improvements in Senegal[20]

Tags: sensitivity analysis | cattle | Africa

What data needs were addressed? To identify the most important parameters through sensitivity analysis of the IPCC Tier 2 model.

Why was the data needed? Having applied the IPCC Tier 2 method to country-specific data, researchers wanted to identify the most important factors driving emissions in order to prioritize future data improvements and research efforts so as to improve livestock GHG emission estimates and reduce the uncertainty of estimates for Senegal.

Methods used: Sensitivity analysis using regression methods.

How was the data need addressed? Senegal is a tropical country in West Africa, with an estimated cattle population of 3.4 million. Extensive livestock systems in Senegal are based on two main breeds of cattle: zebu *Gobra* (*Bos indicus*) in the North and taurine *Ndama* (*Bos taurus*) in the South. Together, these two breeds account for about 90% of the cattle population. To quantify emissions from these breeds using the IPCC Tier 2 model, a variety of data sources were used to derive input values. Information mainly came from two national livestock research centers (the *Centre de Recherches Zootechniques de Dahra*, CRZD and the *Centre de Recherches Zootechniques de Kolda,* CRZK, which are located in the sylvopastoral and agrosylvopastoral zones of Senegal, respectively). Both research centers frequently collect data through surveys and direct measurements on reproductive (e.g. fertility, calving) and productive (e.g. live weight, weight gain, milk yield) performance of cattle. Consequently, research reports, theses, publications and data from partnerships with international research organizations (e.g. FAO, ILRI, ITC) were used, together with documents from the Livestock Ministry of the Senegalese Government and Regional Centres on Agricultural Statistics. When local information was not available, expert judgement (e.g. for proportion of breeds in the cattle herd) or IPCC default values were used. Tables 1 and 2 show the input values used in the Tier 2 models for lactating cows and draft oxen.

Table 1: Assigned values of input parameters in the Tier 2 model for Gobra and Ndama lactating cows

Parameter	Symbol	Unit	Used value	
			Gobra	Ndama
Average daily weight gain	ADG	kg/day	0.135	0.110
Coefficient	C	dimensionless	0.8	0.8
Activity coefficient	Ca	MJ/day/kg	0.36	0.36
Maintenance coefficient	Cfi	MJ/day/kg	0.386	0.386
Pregnancy	Cp	dimensionless	0.10	0.10
Feed digestibility	DE	%	50	50
Fat content of milk	Fat	%	4.7	4.24
Average life body weight	LW	kg	250	200
Milk yield	Milk	kg/day	0.922	0.870
Mature life body weight	MW	kg	200	180
Methane conversion rate	Ym	%	6.5	6.5

[20] This inventory practice note was contributed by Séga Ndao, El Hadji Traore and Mamadou Diop. For further information, contact ndaosega@gmail.com.

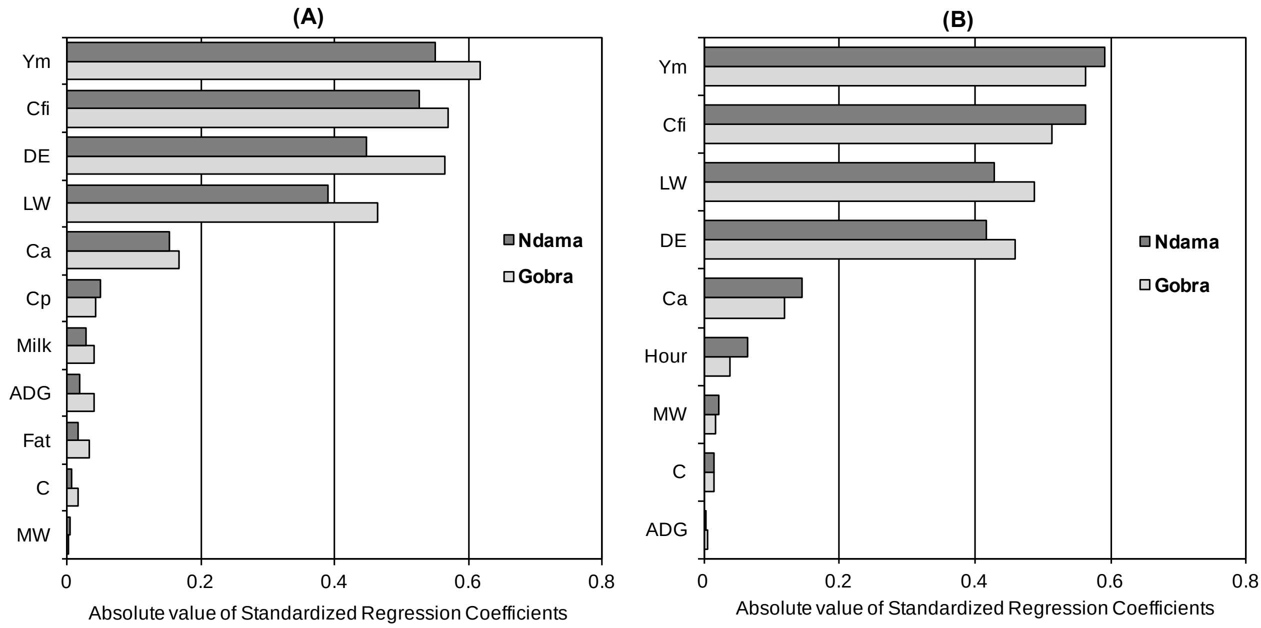
Table 2: Assigned values of input parameters in the Tier 2 model for Gobra and Ndama draft ox

Parameter	Symbol	Unit	Used value	
			Gobra	Ndama
Average daily weight gain	ADG	kg/day	0.135	0.110
Coefficient	C	dimensionless	1.2	1.2
Activity coefficient	Ca	MJ/day/kg	0.36	0.36
Maintenance coefficient	Cfi	MJ/day/kg	0.37	0.37
Feed digestibility	DE	%	50	50
Average amount of work	Hour	h/day	1.23	1.23
Average life body weight	LW	kg	300	250
Mature life body weight	MW	kg	200	180
Methane conversion rate	Ym	%	6.5	6.5

The purpose of conducting sensitivity analysis was to identify which parameters used in the development of methane enteric emission factor require additional research in order to reduce output uncertainty. To do this, the 'sensitivity' package (Pujol et al., 2012) implemented in R software (version 3.3.3) was used. First, we defined the possible ranges of values for each parameter and values were generated between the minimum and the maximum of each parameter used in the sensitivity analysis. For all parameters (e.g. milk, liveweight), we assumed a uniform distribution (with a 95% confidence interval) of ± 20% around each used value. These values were input into the IPCC model to produce a range of values for the output (i.e. annual methane enteric emissions per head). Finally, a regression technique was performed to obtain sensitivity indices (i.e., standardized regression coefficient) for each parameter in the model.

The linear regression method shows sensitivity indices for each input parameter used to estimate enteric methane EF (Figure 1). Overall, the results reveal that for lactating cows and draft oxen the methane conversion rate (Y_m), the coefficient for calculating net energy for maintenance (Cf_i), digestible energy (DE) and liveweight (LW) are the most important parameters affecting the estimated emission factors. Thus, future research should prioritize producing improved estimates of these parameters. While there is relatively more information on live weight and feed digestibility in the Sub-Saharan Africa region, very little research has been conducted on methane conversion rates or other coefficients in the IPCC model. Direct measurements of methane output per unit of feed intake using SF_6 tracer techniques or respiration chambers would be necessary to improve estimates of cattle methane emissions in Senegal.

Figure 1: Standardized regression coefficients of input parameters used to calculate enteric methane emission factors for lactating cows (figure A) and draft oxen (figure B) of Gobra and Ndama cattle



Further resources

Faivre, R., Iooss, B., Mahévas, S., Makowski, D., & Monod, H. (2013). Analyse de sensibilité et exploration de modèles : application aux sciences de la nature et de l'environnement. Editions Quae.

Hamby, D. M. (1994). A review of techniques for parameter sensitivity analysis of environmental models. Environmental monitoring and assessment, 32(2), 135-154.

Iooss, B. (2011). Revue sur l’analyse de sensibilité globale de modèles numériques. Journal de la Société Française de Statistique, 1(152), 3-25.

IPCC. (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories:Approaches to data collection. Volume 1, Chapter 2. International Panel on Climate Change. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/1_Volume1/V1_2_Ch2_DataCollection.pdf.

Makowski, D., Naud, C., Jeuffroy, M. H., Barbottin, A., & Monod, H. (2006). Global sensitivity analysis for calculating the contribution of genetic parameters to the variance of crop model prediction. . Reliability Engineering & System Safety, 10(91), 1142-1147.

Pujol, G., Iooss, B., & Janon, A. (2012). The R package "sensitivity", version 1.6-1. CRAN, Technical report.

Saltelli, A. (2002). Sensitivity analysis for importance assessment. Risk analysis, 22(3), 579-590.

Inventory practice: Uncertainty analysis to prioritize further research in New Zealand

Tags: Uncertainty analysis | meta-analysis | statistical analysis | Oceania

What data needs were addressed? To understand the contribution of key factors to inventory uncertainty and provide an improved estimate of overall uncertainty of the livestock inventory.

Why was the data needed? In 2008, the estimated uncertainty in the national enteric methane (CH_4) emission inventory was ±53%, which was far greater than the estimate for other similar countries. Previous uncertainty analysis conducted in the early 2000's had identified that uncertainty in the quantity of CH_4 produced per unit of feed consumed had a significant impact on overall uncertainty estimates. Since the early 2000's, the number of related measurement studies had greatly increased and a larger pool of data was available to reassess the related uncertainty.

Methods used: meta-analysis of research data, analysis of statistical uncertainty.

How was the data need addressed?

(1) Meta-analysis of experimental measurements using the SF6 method and caliometry showed that the mean methane yields were similar between sheep of different ages (<1 year and >1 year) and between sheep and cattle;

(2) Analysis of the coefficient of variation in methane yield enabled a revised estimate of uncertainty in the overall livestock enteric methane inventory, which was estimated at ±16%.

(3) Analysis of uncertainty in the methane yield measurement data suggested that in order to reduce uncertainty of the methane yield parameter from 3% to 2%, an additional 400 measurements from 5 experiments would be required, but uncertainty of the overall enteric fermentation inventory would only reduce by 1%.

(4) Analysis of data on methane yield and feed intake as a proportion of energy requirements suggested that methane yield may be inversely proportional to the level of feed intake. The study concluded that further research on this topic is required, because if this relationship is established, then the method used in the inventory to estimate methane yield may need revision.

Further resources:

Kelliher, F.M., Clark, H., Smith, M.H., Lassey, K.R. and Sedcole, R., 2009. Reducing uncertainty of the enteric methane emissions inventory. *A report prepared for the New Zealand Ministry of Agriculture and Forestry, Wellington*. Available at: https://www.mpi.govt.nz/dmsdocument/2935/loggedIn

Inventory practice: Analysis of uncertainty in Canada's livestock inventory

Tags: Uncertainty analysis | Monte Carlo analysis | sensitivity analysis | North America

What data needs were addressed? To understand the contribution of key factors to inventory uncertainty and provide an improved estimate of overall uncertainty of the livestock inventory.

Why was the data needed? Until 2013, uncertainty of livestock emission sources in Canada's inventory was estimated using default estimates of uncertainty from the IPCC. An improved estimate of uncertainty was needed for the inventory based on the actual data used in the inventory.

Methods used: Monte Carlo analysis, sensitivity analysis.

How was the data need addressed? A study published in 2012 (Karimi-Zindashty et al. 2012) applied Monte Carlo methods to methane emissions from the Canadian inventory, estimating uncertainty of 38% for enteric fermentation and 73% for methane emissions from manure management. That study identified the methane conversion rate (Y_m), the coefficient for calculating net energy for maintenance (Cf *i*) and the methane conversion factor (MCF) – which all used the IPCC default values – as the greatest sources of uncertainty. It also highlighted that assigning uncertainty values to regional (provincial) parameters would reduce the uncertainty significantly.

For the national inventory, methods based on those used in the 2012 study were applied, but using the actual parameter values and equations used in the inventory. The inventory uncertainty analysis also assessed the uncertainty associated with the duration of different production stages for beef cattle that are defined in the Canadian inventory, and used the provincial distribution of manure management systems with improved estimates of probability distributions. The analysis was run for 1990, 2005, 2010 and 2012, and trend analysis was carried out to establish the uncertainty in the estimate

of the differences in emissions from 1990 to 2012.

The results showed that the uncertainty of enteric fermentation emissions was 39%-40% in different years, and mostly due to cattle emissions, since these are the largest emission source.Trend analysis suggests that emissions of methane increased between the 1990 base year and 2012 by 9 to 19%, with a most likely value of 15% (trend uncertainty 10%), mostly due to enteric fermentation. Similar to the findings from Karimi-Zindashty et al. (2012), the inventory analysis of uncertatiny suggests that the IPCC default parameters (i.e., the methane conversion rate (Ym) and the factor associated with the net energy of maintenance (Cfi)) contribute most significantly to uncertainty. These parameters are applied at the national scale, so uncertainty might be reduced by developing parameter values at the regional scale for different animal categories.

Further resources:

Karimi-Zindashty, Y., MacDonald, J.D., Desjardins, R.L., Worth, D.E., Hutchinson, J.J. and Vergé, X.P.C., 2012. Sources of uncertainty in the IPCC Tier 2 Canadian livestock model. *The Journal of Agricultural Science*, *150*(5), pp.556-569.

Canada NIR 2017

Inventory practice: UK's GHG R&D Platform supports inventory improvements

Tags: Institutional arrangements | Europe

In recent years, the UK's Department for Environment, Food and Rural Affairs has supported an inter-related set of research projects aimed at delivering an improved Tier 2/Tier 3 inventory for agriculture. Specific projects are summarized in the table below. Together, these research projects funded:

- Reviews of existing research;
- Collection and analysis of new data;
- disaggregation of the UK Agricultural Survey and farm practice data according to a typology of representative farm systems so as to be able to apply higher resolution EFs;
- Improved inventory methodologies; and
- The implementation of new data and methodologies in the national inventory.

Project code	Project title	Summary of contents
AC0115	GHG R&D Platform Methane emission factors	Aim: to develop new EFs by exploiting existing datasets held by partner organisations on measurements of ruminant methane emissions; new EFs will then be aligned with spatial and temporal disaggregation of UK farming systems to improve the precision of GHG inventory reporting.
AC0116	GHG R&D Platform Nitrous oxide emission factors	Aim: to develop new EFs from direct measurements of N_2O in order to better reflect management systems within the UK, taking account of the range of soil types and climate, and to reflect potential mitigation methods
AC0114	GHG R&D Platform Data management	Aim: to provide fundamental improvements in the accuracy and resolution of the UK National Inventory and the development of a more detailed reporting methodology though an intensive period of coordinated exploration, synthesis and modelling of existing data from across the scientific community and industry data holders
SCF0102	Delivering the agricultural GHG and ammonia inventories	Aim: to deliver annual inventories of ammonia and GHGs to Defra on a timely basis and annual updates of projected emissions. The project will compile the GHG inventory using the UKs current Tier 1 approach whilst developing an operational Tier 2/3 inventory in accordance with the guidance and evolving outcomes of the GHG R&D Platform.

Further resources:

UK 2017 NIR

Agricultural GHG inventory research platform: http://www.ghgplatform.org.uk/Home.aspx