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Benchmarking the emissions intensity of Scottish livestock–derived agricultural commodities

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Executive Summary

This project was commissioned to help Scottish Government explore how the agricultural sector can contribute to reducing greenhouse gas emissions in line with the targets under the Climate Change (Scotland) Act 2009. This report examines the approaches for quantifying emissions, reviews recent studies and provides recommendations on benchmarking. The aim is to perform repeated comparisons of the emissions intensity (EI) of Scottish agricultural commodities with other countries.

Findings

- Most estimates of GHG emissions follow methods established by the Intergovernmental Panel on Climate Change (IPCC, 2006a).
- There is a growing body of literature on the GHG emissions arising from food supply chains, with an emphasis on (a) cattle, pigs and chickens, (b) developed countries and (c) emissions arising up to the farm gate. The majority of these studies focus on one species in a particular country and do not include post-farm processes.
- While such studies are valuable, differences in approach (i.e. in terms of scope, input assumptions and calculation method) can make comparisons between species and countries difficult.
- The types of data required for benchmarking depend on a range of factors, such as: (a) the level of disaggregation, i.e. the extent to which the analysis needs to capture differences between production systems, locations etc.; (b) the system boundary, e.g. cradle to grave, cradle to farm etc.; (c) the scope, i.e. which processes and emissions categories are included; (d) the desired validity; and (e) the purpose of the analysis.

Recommendations

The report looks at which emissions categories to include in the benchmarking, and how they could be quantified:

1. The initial focus should be on benchmarking cattle milk and meat, and sheep meat because of the significant contribution they make to Scotland's agricultural GHG emissions.
2. The system boundary should be cradle to farm-gate, in the first instance.
3. A second phase of work should be undertaken to determine the availability of data in Scotland and two or three potential comparator countries.

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Introduction

Agriculture (and related land use) contributed 23% of Scotland's greenhouse gas emissions (GHG) in 2013 (see Salisbury et al. 2015). The Scottish Government is exploring policies which can contribute to the reduction targets arising from the Climate Change (Scotland) Act 2009 and would like to be able to perform repeated comparisons of the emissions intensity (EI) of Scottish agricultural commodities with other countries. This project explains the approaches for quantifying emissions, reviews recent studies and provides recommendations on how benchmarking could be undertaken.

Overview of methods for quantifying GHG emissions from food supply chains

Most estimates of GHG emissions follow methods established by the Intergovernmental Panel on Climate Change (IPCC, 2006a). The IPCC guidance provides a choice of methods for quantifying emissions, from the relatively simple Tier 1 approach to more complex Tier 2 or 3 approaches. Tier 2 or Tier 3 approaches are more demanding but can provide useful insights into the drivers of GHG emissions. In theory, a Tier 2/3 approach should provide more accurate and informative results, which better reflect the differences between production systems. This is particularly true for livestock where the Tier 2 calculations of emission factors are based on a wide range of parameters, whereas the Tier 1 approach employs default emission factors. The Tier 2 approach also provides greater scope for predicting the effect of mitigation measures on EI, by varying selected parameters.

In recent years, several tools have been developed to support the quantification of agricultural GHG emissions (Schils *et al.* 2007, Crosson *et al.* 2011). The World Resources Institute (2014, p88) lists over 40 such tools, ranging from fairly simple and user-friendly carbon calculators to more complex process-models such as DNDC and DayCent. The range of tools is expanding to meet the needs of specific users. For example, to help farmers in the UK to benchmark their performance and identify practical steps they can take to reduce emissions AgRECalc (http://www.agrecalc.com/) has been developed. On a broader scale, the European Commission Joint Research Centre (2015) has developed a carbon calculator designed for assessing the life cycle GHG emissions from different types of farming systems across the EU.

The IPCC Guidelines for agricultural emissions

Many carbon calculators and models are based on the methods set out in volume 4 ("Agriculture, Forestry and Other Land Use") of the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC 2006a). These guidelines were developed to support the United Nations Framework Convention on Climate Change (UNFCCC), which requires signatory nations to establish and regularly update a national GHG inventory (see Appendix A). They take a territorial approach to reporting, that is, they are based on economic activity that occurs within a defined territory. Volume 4 (IPCC 2006a) provides guidance for quantifying emissions from Agriculture, Forestry and Other Land Use, see Table 1.

Table 1 Emissions categories in Volume 4 of IPCC (2006a)

Source	Gas
Emissions and removals resulting from C stock changes in biomass, dead organic matter and mineral soils, for all managed lands;	CO_2
Emissions from fire on all managed land;	CO_2 and non-CO_2
Emissions from all managed soils;	N_2O
Emissions associated with liming and urea application to managed soils;	CO_2
Emissions from rice cultivation;	CH_4
Emissions from cultivated organic soils;	CO_2 and N_2O
Emissions from managed wetlands;	CO_2 and N_2O
Emission from livestock enteric fermentation;	CH_4
Emissions from manure management systems;	CH_4 and N_2O
C stock change associated with harvested wood products.	CO_2

Key features of the guidance include: (a) an introduction to the emissions source (b) an overview of the alternative methods for quantifying the emissions (Tier 1, Tier 2, Tier 3), (c) flow diagrams to aid method selection, (d) formulae required to undertake the Tier 1 and Tier 2 calculations, (e) default values for some key parameters (such as methane conversion factor and nitrogen excretion rates), and (f) uncertainty ranges for key parameters. A brief explanation of the Tier 1, 2 and 3 approaches is given in Appendix B. Emissions estimates based on Tier 2 or Tier 3 approaches are more complex and demanding, but can provide useful insights into the drivers of GHG emissions. However, even when these more complex methods are used, the national GHG inventories still have certain limitations:

- agricultural activities are modelled as separated rather than integrated processes;
- temporal links are not fully captured, which can make it difficult to represent multi-annual processes such as crop rotations;
- the inventories estimate total emissions rather than emission intensities (i.e. emissions per unit of output).

The last point means that the inventories reflect both the *scale* of activities and (when Tier 2 or 3 approaches are used) the *efficiency* with which the activities are undertaken. While they undoubtedly provide useful information to governments regarding the relative importance of different sectors within their policy ambit, they can be misleading as changes in emissions can arise from changes in the scale of agricultural activity rather than in emissions intensity. We therefore need to supplement the estimates of total emissions with estimates of emissions intensity. Potential measures of emissions intensity are summarised in Table 2.

Table 2. Measures of emissions intensity and functional units (FU) for food and drink products

Measure of emissions intensity	Functional unit	Summary
$kgCO_2e$/country/year	Territory	The metric used in current national GHG inventories. Useful for identifying the contribution of different sectors, but provides no information regarding the efficiency of production.
$kgCO_2e$/ha/year or $kgCO_2e$/head/year	Land area or number of livestock	Useful for identifying the contribution of different locations or land types, but provides no information regarding the efficiency of production.
$kgCO_2e$/kg LW	Total mass of LW produced	Can be used when the system boundary is the farm gate. Avoids the challenges of allocating emissions to different slaughter co-products (meat, offal, tallow etc.) but doesn't reflect differences in these processes/products between commodities, systems and locations.
$kgCO_2e$/kg product	Total edible mass	Commonly used FU, which enables the emissions intensity of the same product to be studied in different locations and systems. Of limited use in comparing products with different nutritional properties.
$kgCO_2e$/kg protein	Mass of edible protein	As for total mass, with the added advantage that they express results for products with different nutritional properties in ways that enable like-for-like comparison.
$kgCO_2e$/MJ DE	Digestible energy content	
$kgCO_2e$/£ GVA	Economic value	A useful FU where the primary function of production is economic growth. It can be difficult to interpret its meaning in practice, e.g. decrease in EI over time could be due to change in (a) efficiency of production or (b) increase in value, or both.

Ultimately, a good functional unit reflects the function the product or activity performs in a particular context - the same product can have different functions in different contexts, e.g. where diets are protein deficient it may be appropriate to use kg protein as the FU for food products (instead of total mass or energy content). Similarly, different foods can perform different functions within the same context, e.g. staple foods (such as bread or potatoes) perform a different function to non-staple foods (such as chocolate or whisky).

Moving beyond the farm gate: life-cycle analysis

The agricultural emissions quantified by many models are essentially those arising on-farm. However, farms do not exist in isolation. The production of food, fuel and fibre involves complex supply chains, which deliver inputs to the farm (such as energy, fertiliser and machinery) and transport and transform farm outputs to meet consumer demand (see Table 3). Limiting our analysis to on-farm emissions can therefore omit important processes, providing a partial view of the full impact and ignoring opportunities for mitigation. In order to avoid this, we can use life-cycle analysis (LCA).

Table 3. Examples of pre and post-farm processes

Pre-farm	Post-farm
Production of crop feed materials Production of non-crop feeds (e.g. synthetic additives, fishmeal). Fertiliser manufacture Feed blending Production of fuel and electricity Manufacture of capital goods Transportation of inputs	Transportation and processing of commodities Manufacture of packaging Retail Consumption Waste management

Why use life-cycle analysis?

LCA helps to avoid simply shifting the burden to another part of the supply chain. For example, swapping a petrol car for an electric car reduces the exhaust emissions dramatically. However, it also leads to additional impacts upstream and downstream arising from the manufacture, charging and disposal of the battery, and these need to be included to make a valid comparison. In theory LCA provides an assessment of the total burden required for a product and enables a clearer picture of where burdens are arising along supply chains, thereby improving efficiency of production, informing consumer choices and enabling more efficient policy-making.

LCA is commonly divided into two types: (a) attributional LCA, which describes the situation that currently exists, and (b) consequential LCA, which is predictive and tries to answer "what if…?" questions. Table 4 provides examples of the sorts of questions that can be answered with attributional and consequential LCA.

Table 4. Examples of the sorts of questions that can be answered with attributional and consequential LCA.

Attributional or descriptive	Consequential or predictive
• What is the total life cycle impact of a commodity, e.g. UK or global sugar production, and what contribution do different processes make? • How do 2 different commodities compare, e.g. UK beef v UK lamb • How does the same commodity, produced in different locations and/or systems compare, e.g. UK lamb v New Zealand lamb, free range eggs v cage eggs, fresh fish v frozen fish?	What happens if… • A farm converts to organic? • Nuclear power stations are replaced with coal? • Recyclable packaging is introduced? • GM feed soy is banned? • New welfare regulations for laying hens are introduced? • A disease eradication scheme is introduced?

Predictive analysis – quantifying the effects of mitigation measures on EI

In theory, a tier 2 approach to calculating on-farm emissions should provide more accurate and informative results, which better reflect the differences between production systems. This is particularly true for livestock where the tier 2 calculations of emission factors are based on a wide range of parameters (see Figure B1), whereas the tier 1 approach employs default emission factors. The tier 2 approach also provides greater scope for predicting the effect of mitigation measures on EI, by varying selected parameters.

Review of recent studies

There is a growing body of literature on the GHG emissions arising from food supply chains. Appendix D provides a (non-exhaustive) list of references on livestock systems that have been published over the last 10 years or so to illustrate the range of studies. The focus tends to be on (a) cattle, pigs and chickens, (b) developed countries and (c) emissions arising up to the farm gate – the majority of these studies do not include post-farm processes. Most of the studies focus on one species in a particular country. While such studies are valuable, differences in approach makes it difficult to investigate variations between species and countries. However, some studies are available that enable comparison of different species across a range of countries (see Lesschen *et al.* (2011), Weiss and Leip (2011), Opio *et al.* (2013) and MacLeod *et al.* (2013), Tubiello *et al.* (2014)). The scope and methods employed in these studies are summarised in Table 5.

The results of recent studies of cow's milk, beef and sheep/goat meat are summarised in Table 6. Where available, the results from GLEAM are also given. There are several reasons why two studies may come up with different results for the same commodity produced in the same location. Often discrepancies can be explained with reference to the different methodologies and assumptions employed, in particular:

- Scope of the analysis (i.e. the system boundary and the emissions categories included).
- On-farm GHG method for calculating feed intake and enteric methane emissions (tier 1 v tier 2 or 3)
- Assumptions made about animal performance: milk yield, dairy cow weight, beef cattle weight etc.
- Assumptions about the composition of the ration – enteric methane emissions are sensitive the digestibility of the ration, particularly at low levels of digestibility.
- Assumptions made about fertiliser application rates and nutrient use efficiency in crop production.
- The method use to calculate emissions arising from land use change (LUC).
- Allocation to co-products (e.g. crops and crop residues, or wool and sheep meat).
- Assumptions about how manure is managed.
- The year the analysis is undertaken for as results can be time sensitive (indeed this is one of the reasons why repeated benchmarking is a worthwhile activity) because of changes in, for example, deforestation rates, fertiliser prices (and application rates).

Table 5. Scope and methods of recent supranational studies.

	Base year	Geog. scope	Reporting unit	System boundaries	Commodities	Livestock GHG method	Herd model?
Lesschen *et al.* (2011)	2004	EU-27	Country	Mainly on-farm, plus some pre-farm (fertiliser production)	Meat & milk from cattle, pork, poultry meat and eggs.	CAPRI[a] and GAINS[b] supplemented with soil C and N leaching modules. Enteric CH_4 T1, manure CH_4 T2.	No
Weiss and Leip (2011)	2004	EU-27	NUTS 2 regions	Cradle to farm-gate: on farm and production of inputs	Meat & milk from cattle, sheep & goat meat and milk, pork, poultry meat and eggs.	Enteric and manure CH_4: T2 for cattle, T1 for other species. Crop/soil N_2O emissions: MITERRA + RAINS[c]	No
Opio *et al.* (2013)	2005	Global	Region	Cradle to retail point	Meat & milk from cattle, meat and milk from sheep & goats, meat and milk from buffalo.	T2 for all species	Yes
MacLeod *et al.* (2013)	2005	Global	Region	Cradle to retail point	Pork, chicken meat, chicken eggs.	T2 for all species	Yes
Tubiello *et al.* (2012, 2014)	1961-2012	Global	Country	On-farm emissions plus on-farm energy use.	No calculation of EI, provides T1 estimates of total emissions for: cattle, buffalo, sheep, goats, camels, mules/asses, horses, pigs, poultry.	T1 for all species	No

a. CAPRI: Common Agricultural Policy Regionalised Impact Modelling System; b. GAINS: Greenhouse Gas - Air Pollution Interactions and Synergies model

c. RAINS: Regional Air Pollution Information and Simulation model

Table 6. Comparison of the emissions intensity (EI) of beef, cow's milk and sheep/goat meat in recent studies. Derived from Tables 14 and 15 in Opio et al (2013). (NA: results not available at time of writing)

			Scope							Emissions Intensity[a]		
Study	Country	Commodity	Enteric CH_4	Manure CH_4	Manure N_2O	Feed N_2O	Feed CO_2	Energy	Post farm	Study	GLEAM	Notes
Casey & Holden (2006)	Ireland	Beef	Y	Y	Y	Y	Y	Y	N	11.3	19.1	$kgCO_2e/kgLW$
Williams *et al.* (2006)	Brazil	Beef	Y	Y	Y	Y	Y	Y	Y	32.2	32.4	
Ogino *et al.* (2007)	Japan	Beef	Y	Y	Y	Y	Y	N	N	32.1	39.0	
Cederberg *et al.* (2009)	Brazil	Beef	Y	Y	Y	Y	Y	Y	N	28.0	32.4	No LUC
Leip *et al.* (2010)	EU27	Beef	Y	Y	Y	Y	Y	Y	N	22.2	24.1	
Leip *et al.* (2010)	UK	Beef	Y	Y	Y	Y	Y	Y	N	20.6	NA	
Foley *et al.* (2011)	Ireland	Beef	Y	Y	Y	Y	Y	N	N	23.1	27.7	
Lesschen *et al.* (2011)	EU27	Beef	Y	Y	Y	Y	Y	N	N	22.6	24.1	kgCO2e/kg beef
Lesschen *et al.* (2011)	UK	Beef	Y	Y	Y	Y	Y	N	N	26.0	NA	

Table 6. (cont)

			Scope							Emissions intensity[a]		
Study	Country	Commodity	Enteric CH_4	Manure CH_4	Manure N_2O	Feed N_2O	Feed CO_2	Energy	Post farm	Study	GLEAM	Notes
Casey and Holden (2005)	Ireland	Cow's milk	Y	Y	Y	Y	Y	Y	N	1.5	1.8	
Williams *et al.* (2006)	UK	Cow's milk	Y	Y	Y	Y	Y	Y	N	1.2	1.5	
Thomassen *et al.* (2008)	Netherlands	Cow's milk	Y	Y	Y	Y	Y	Y	N	1.4	1.6	
Flysjo *et al.* (2011)	New Zealand	Cow's milk	Y	Y	Y	Y	Y	Y	N	1.0	1.5	No LUC
Flysjo *et al.* (2011)	Sweden	Cow's milk	Y	Y	Y	Y	Y	Y	N	1.2	2.5	No LUC
Hagemann *et al.* (2011)	EU19 countries	Cow's milk	Y	Y	Y	Y	Y	Y	N	1.2	1.6	No LUC
Henricksson *et al.* (2011)	Sweden	Cow's milk	Y	Y	Y	Y	Y	Y	N	1.1	2.5	No LUC
Kristensen *et al.*, (2011)	Denmark	Cow's milk	Y	Y	Y	Y	Y	N	N	1.2	1.5	No LUC
Lesschen *et al.* (2011)	EU27	Cow's milk	Y	Y	Y	Y	Y	N	N	1.3	1.6	
Chayer *et al.* (2012)	Canada	Cow's milk	Y	Y	Y	Y	Y	Y	N	1.0	1.4	
Christie *et al.* (2012)	Australia	Cow's milk	Y	Y	Y	Y	Y	Y	N	1.0	1.8	No LUC
DairyCo (2012)	UK	Cow's milk	Y	Y	Y	Y	Y	Y	N	1.3	1.5	No LUC
Weiss and Leip (2012)	EU27	Cow's milk	Y	Y	Y	Y	Y	Y	N	1.4	1.6	
Thoma *et al.* (2013)	USA	Cow's milk	Y	Y	Y	Y	Y	Y	Y	2.1	1.7	Includes consumption
Leip *et al.* (2010)	EU27	Sheep/goat meat	Y	Y	Y	Y	Y	Y	N	20.3	18.1	
Leip *et al.* (2010)	UK	Sheep/goat meat	Y	Y	Y	Y	Y	Y	N	23.6	NA	
Ripoli –Bosch *et al.* (2010)	Spain	Sheep/goat meat	Y	Y	Y	Y	Y	Y	N	56.7	25.9	Grazing
Ripoli –Bosch *et al.* (2010)	Spain	Sheep/goat meat	Y	Y	Y	Y	Y	Y	N	48.5	NA	Mixed
Ledgard *et al.* (2011)	New Zealand	Sheep/goat meat	Y	Y	Y	Y	Y	Y	Y	19.0	14.8	Allocation to wool
Ledgard *et al.* (2011)	New Zealand	Sheep/goat meat	Y	Y	Y	Y	Y	Y	Y	19.0	19.0	No allocation to wool

a. Unless otherwise noted, the emissions intensities are expressed in $kgCO_2e/kgCW$ for beef and sheep/goat meat, and $kgCO_2e/kg$ milk for cow's milk.

Scoping/feasibility study

The purpose of this section is to provide an assessment of what would be required to undertake repeated calculations of the EI of livestock commodities produced in Scotland and a panel of comparator countries. Section 4 provides specific preliminary recommendations on how the benchmarking should be approached.

Commodities, functional units and system boundaries

Decisions need to be made regarding the details of the benchmarking, i.e.:

- Which commodities are to be benchmarked: beef, sheep meat and dairy cattle?
- Which products and functional units: e.g. for beef, do we want to measure the EI in terms of the following or some other functional unit:
    - kg CO_2e/kgLW_at farm_gate
    - kgCO_2e/kg_bone_free_meat_at_retail_point
- Which system boundaries?

The choice of system boundary depends on the products being analysed. Post-farm processes can be challenging to quantify accurately and, for red meat products, have a fairly small influence on the emissions intensity. However for other products, such as milk and cheese, significant emissions can arise post-farm gate, primarily from energy use, see Figure 2.

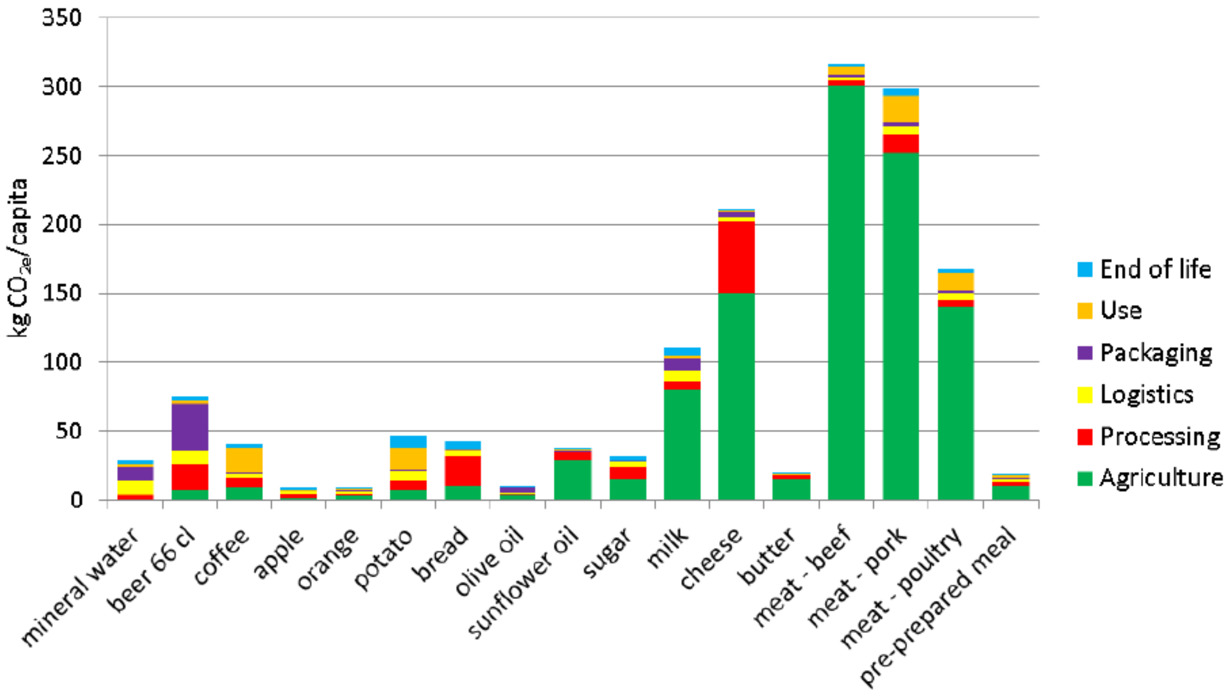

Figure 2. Annual greenhouse gas emissions related to the average EU citizen's consumption of the JRC food basket, detailed per product and per production step (European Commission Joint Research Centre 2015, p24).

Which countries should Scotland be benchmarked against?

Table 7. The top ten producers of cattle and sheep meat in the EU in 2013 (meat is dressed carcass weight, excluding offal and slaughter fats) Source: FAOstat, 6/10/15.

Member state	Cattle meat production (t)	Cumulative %	Member state	Sheep meat production (t)	Cumulative %
France	1,400,400	19%	UK	289,000	34%
Germany	1,106,395	34%	Spain	118,261	48%
UK	847,000	45%	France	110,936	61%
Italy	842,122	57%	Greece	77,000	70%
Spain	580,840	65%	Romania	68,108	78%
Ireland	517,580	72%	Ireland	57,470	84%
Poland	386,000	77%	Germany	34,737	89%
Netherlands	373,760	82%	Italy	34,154	93%
Belgium	249,973	85%	Netherlands	12,115	94%
Austria	228,903	88%	Bulgaria	10,599	95%

Performing the calculations

Quantifying EI involves a series of calculations, as outlined in Table 8. Most of these calculations can be readily performed in a spreadsheet package such as excel. The spreadsheet can be designed in such a way as to enable multiple scenarios (tens or even hundreds) can be run simultaneously through a standard spreadsheet package, although there is limited capacity to take into account spatial variation in key parameters, such as stocking density, manure application rates, ambient temperature and crop yields. If spatial analysis is required, calculations can be performed in a Geographical Information System (GIS) by converting the formulae into a GIS-compatible language (e.g. Python or R) and compiling the required spatial data layers, such as:

- Livestock distributions – Gridded Livestock of the World. Within Europe, IACS data.
- Ambient temperature
- Leaching rates
- Pasture availability/quality

The GIS approach is more resource intensive, but provides spatially explicit analysis and greater flexibility in combining datasets and aggregating results.

Table 8. Overview of the steps in calculating livestock commodity EI

Pre-farm emissions Determination of EFs for pre-farm inputs (energy, fertiliser, capital goods). Determination of the rate of consumption of pre-farm inputs.
Determination of herd dynamics Calculation of the herd structure, i.e. the proportion of animals in each cohort, and the rate at which animals move between cohorts. Calculation of the characteristics of the animals in each cohort, i.e. the average weights and growth rates.
Feed parameters and emissions Determination of the composition of the ration for each species, cohort and system. Calculation of the nutritional values of the ration per kg of feed dry matter (DM). Calculation of the GHG emissions per kg of feed, which involves: • determination of the rates at which organic and synthetic N is applied to crops; • determination of rates of energy use in fieldwork, processing and transport; • calculation of land use change; • determination of crops yields; • allocation of emissions between crop co-products, i.e. grains, crop-residues and crop by-products (brans, meals etc.); • EFs for non-crop feed materials (e.g. lime, synthetic additives, fishmeal).

Feed intake, enteric and manure emissions Calculation of the average energy requirement and feed intake of each animal cohort. Calculation of volatile solid and N excretion rates. Calculation of the total emissions and land use arising from the production, processing and transport of the feed. Calculation of the CH_4 and N_2O emissions arising during the management of manure; Calculation of enteric CH_4 emissions.
Allocation and calculation of EI Calculation of the production of commodities (meat, milk, eggs and fibre). Allocation of the emissions to the edible outputs, non-edible outputs (slaughter by-products, fibre and manure) and services (e.g. draft power). Calculation of EI of each commodity.
Post-farm emissions Determination of emissions arising from, e.g. post-farm transport, processing and packaging.

Developing a bespoke tool to quantify EI requires significant time, resources and expertise. There are a range of publically-available tools that can calculate the EI of agricultural commodities, however, as far as we aware, there currently are no publically available tools that have the capacity to adequately capture the effects of herd structures on EI. GLEAM (see Appendix E) can capture these effects, but is not currently publically available. However, an excel-based version of GLEAM has been developed and is being tested at the moment prior to being made publically available online within the next twelve months (see Appendix F). This version will enable users to enter values for a range of herd parameters, specify the rations and manure management systems, and extract results for total emissions and emissions intensities, disaggregated in various ways. It will be possible to enter values for the following herd parameters into the online GLEAM:

- Age at first calving
- Fertility of adult females
- Mortality of young females
- Mortality of young males
- Mortality of adult animals
- Replacement of adult females
- Weight at birth
- Weight of adult females.
- Weight of adult males
- Weight of fattening females
- Weight of fattening males
- Milk production
- Milk fat content.
- Milk protein content.

Gathering quality data for all of these parameters is a challenging task. A useful first step would be to prioritise the data gathering by identifying the most important parameters via sensitivity testing. The sensitivity of the EI to a given parameter will depend on the specific details of the system, for example in dairy systems the sensitivity will depend on whether or not sexed semen is used, baseline milk yield etc. In general, the EI of milk will be most sensitive to milk yield and cow fertility rates. In suckler beef and sheep systems the EI will tend to be sensitive to cow/ewe fertility and abortion rates, calf/lamb mortality and growth rates. The EI of all systems are likely to be sensitive to ration composition and rates of feed conversion as these affect both the emissions arising from feed production and the emissions arising from excretion (of volatile solids and nitrogen).

While the proposed online GLEAM enables some important parameters to be specified, it will not be possible to vary others, such as crop yields or nutrient application rates. Despite this, the proposed online GLEAM has several advantages:

- It enables key herd parameters to be specified and their effect on EI to be explored.

- It can be used to analyse the main livestock species and systems.
- It can be used to analyse production in any country.
- The results should be more transparent to the Scottish Government as SRUC staff were involved in the development of GLEAM, and can explain the details of the method used in it.

Input data required and data available

The data required to calculate the emissions intensity using a tier 2 type approach depends on a range of factors, such as: (a) the level of disaggregation, i.e. the extent to which the analysis needs to capture differences between production systems, locations etc.; (b) the system boundary, e.g. cradle to grave, cradle to farm etc.; (c) the scope, i.e. which processes and emissions categories are included; (d) the desired validity; and (e) the purpose of the analysis. For example, if the purpose of the model is descriptive, i.e. to estimate the EI of beef production under current conditions, then a herd model (and the herd parameters required for it) may not be necessary as the herd structures (i.e. the number of animals in each age/sex cohort) may be determined from recorded statistics. However, if the model is required to do predictive analysis, i.e. to estimate the EI under changed conditions, then a herd model enables the effect of changed genetics or health on EI to be predicted by changing parameters such as fertility rates or mortality rates.

The parameters required to undertake tier 2 type calculations and potential data sources are described briefly in Appendix G.

Preliminary recommendations on benchmarking Scottish agricultural commodities

Priority commodities

The initial focus should be on benchmarking cattle milk and meat and sheep meat because of the significant contribution they make to Scotland's agricultural GHG emissions. In 2013 cattle and sheep produced 99% of the enteric and manure GHG emissions within Scotland (see Salisbury *et al.* 2015) and a significant % of the direct soil emissions (these are not quantified for Scotland in the UK inventory submission, but in Ireland's 2013 submission urine and dung deposited by grazing animals produced just under half of the direct N_2O from managed soils).

System boundaries and scope

The system boundary should be cradle to farm-gate, including the emission categories outlined in Table 9. For cattle and sheep meat a small proportion of the emissions occur post-farm gate. For dairy products, post-farm gate processes can account for a more significant proportion of the lifecycle emissions, however we do not recommend inclusion of these in the initial benchmarking, though they may be worth including in the future.

Functional units

Milk: $kgCO_2e$/kg fat and protein corrected milk at the farm gate.
Meat: $kgCO_2e$/kg liveweight at the farm gate.
Additional functional units may be required in order to enable comparison with other studies.

Calculation method and data sources

Table 9 provides recommendations regarding which emission categories should be included in the benchmarking and how they should be quantified. The following points should be noted:

- Different approaches will be needed to quantify emissions from domestically grown crops (where Tier 1 calculations may be readily performed) and imported crops (where default EFs from databases, such as FeedPrint) may be used instead.
- A method is required for determining the herd structure, i.e. the number of animals in each age category. This could be based on reported data or modelled. Whether or not to develop a herd model

depends on (a) the purpose of the benchmarking (description v prediction), (b) the availability of population/production data, and (c) the availability of data to populate the herd model.

- The EI is a function of the emissions and production, therefore a reliable method for determining gross production and production losses (to farm gate) is required. Modelling may be required to augment existing data sets.

It should be possible to use the recommended approach to perform periodic calculations of EI that are geographically (and temporally) consistent. However, data availability may be problematic in some areas, notably:

- Acquiring values for some herd parameters – this may make maintaining herd models challenging. They could be created using existing data sources augmented with expert opinion, but updating them regularly may be challenging.
- Acquiring data on grasslands, e.g. yields, fertiliser application rates, and rates of legume use and biological N fixation within swards.
- Acquiring data on the rate and mode of manure application to land.
- Capturing variation in nutrient use efficiency between countries, i.e. linking nutrient application and yields.
- Taking into account differences in soil management and soil carbon fluxes.
- Acquiring robust data on ration composition and nutritional value.
- Linking ration composition and animal performance.
- Quantifying the EI of by-product feeds, i.e. allocating emissions to distillers' grains.

A pragmatic next step would therefore be to undertake a detailed audit of data availability in Scotland and a small number (2 or 3) of potential comparator countries where data availability is thought to be good (e.g. Ireland or The Netherlands).

Table 9. Recommended approach to quantifying emission categories

Emissions category	**Gas**	**Include?**	**Approach**
Fertilizer manufacture	CO_2	y	Default EF from LCA database.
Direct and indirect N_2O from: application of synthetic N	N_2O	y	T1
Direct and indirect N_2O from: application of manure	N_2O	y	T1
Direct and indirect N_2O from: crop residue management	N_2O	y	T1
N_2O losses related to changes in C stocks	N_2O	n	Not in initial analysis – difficult to determine change in C.
Biomass burning	N_2O	n	Minor source of GHG
Biological fixation	N_2O	n	Not included in IPCC (2006) method.
Energy use in field operations	CO_2	y	Relatively small sources of GHG for cattle and sheep and detailed data likely to be scarce. Use simplified approach: GHG = Activity * default EF
Energy use in feed material processing (e.g. oil extraction)	CO_2	y	
Energy used in feed mill for blending etc.	CO_2	y	
Production of non-crop feeds (e.g. lime and synthetic amino acids)	CO_2	y	EFs from FeedPrint.
CH_4 from flooded rice cultivation	CH_4	n	Not applicable
Land use change (LUC) related to soybean cultivation	CO_2	y	To be discussed – given the impact LUC method can have on EI, sensitivity testing is recommended.
Land use (LU), i.e. changes in carbon stocks from land use under constant management practices	CO_2	n	No consensus on rates of change in carbon stocks, and uncertainty regarding permanence of changes.
Emissions from lime application	CO_2	n	Not in initial analysis – likely to be a minor source of GHG?
Manufacture of feed packaging	CO_2	n	Minor source of GHG
Transport - feed material to processing, processing to feed mill, mill to farm	CO_2	y	Relatively small sources of GHG for cattle and sheep and detailed data likely to be scarce. Use simplified approach: GHG = Activity * default EF
Emissions from manufacture of on-farm buildings and equipment	CO_2	n	Minor source of GHG
Production of cleaning agents, antibiotics and pharmaceuticals	CO_2	n	Minor source of GHG
Enteric fermentation	CH_4	y	T2, challenges may include determining rations and animal performance.
Manure management	CH_4, N_2O	y	
Soil N_2O from direct deposition of N by grazing animals	N_2O	y	T2 for N excretion rates, T1 for calculation of Nx>N_2O
Direct on-farm energy use	CO_2	y	Small source of GHG for sheep and beef, likely to be more significant (but still small) for dairy.
Land use change on cattle/sheep farm	CO_2	y	GHG effects of changing areas of farm woodland could be quantified using the Woodland Carbon Code method.

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Acronyms

BSFP	British Survey of Fertiliser Practice
CAPRI	Common Agricultural Policy Regionalised Impact Modelling System
CTS	The Cattle Tracing System (CTS) is the database for all cattle in Great Britain, to which farmers must notify births, movements and deaths of cattle on their holding.
CW	Carcass weight
EF	Emission factor
EI	Emissions Intensity
FADN	The Farm Accountancy Data Network
FAOstat	Food and Agriculture Organization of the United Nations Statistics
FSS	Farm structure survey
GAINS	Greenhouse Gas - Air Pollution Interactions and Synergies model
GLEAM	Global Livestock Environmental Assessment Model
IACS	Integrated and Administration Control System
IFCN	International Farm Comparison Network
IPCC	Intergovernmental Panel on Climate Change
LCA	Life cycle analysis
LW	Live weight
NIRs	National Inventory Reports
QMS	Quality Meat Scotland
RAINS	Regional Air Pollution Information and Simulation model
SAPM	Survey on agricultural production methods
UNFCCC	United Nations Framework Convention on Climate Change

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Appendix A. Using National GHG Inventory Data

https://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/8108.php

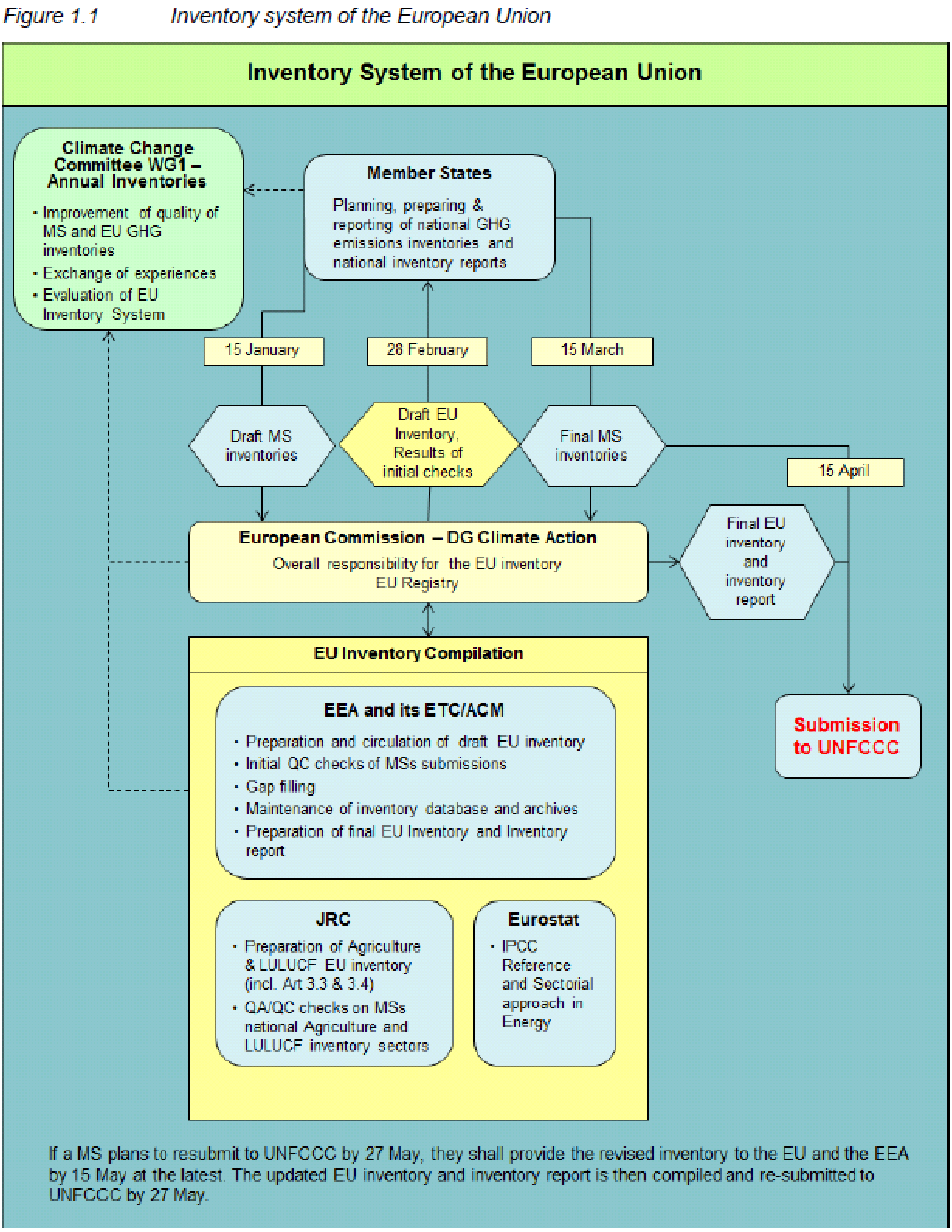
EU member states and other Annex 1 countries (see below) prepare an inventory of their GHG emissions as part of the obligations under the United Nations Framework Convention on Climate Change (UNFCCC). The EU inventory system is illustrated in Figure A1. These inventories provide estimates of the emissions from the agriculture, land use and land use change (ALULUCF) sectors, prepared in accordance with the IPCC guidelines (see IPCC 1996, 2006).

Non-EU28 Annex 1 countries

Australia	Kazakhstan	Russian Federation
Belarus	Liechtenstein	Switzerland
Canada	Monaco	Turkey
Iceland	New Zealand	Ukraine
Japan	Norway	United States

The UK National Inventory uses a Tier 2 approach for cattle, which means that it requires input data for a wide range of livestock parameters. This data is drawn from a variety of sources (see NIR 2014p659-676), including national statistics (such as the Farm Practices Survey and June Census), literature and expert opinion. Some parameters are updated each year (livestock numbers, dairy cow weights, dairy cow milk yields, synthetic N application rates), while others are updated on a more irregular *ad hoc* basis. It should be noted that the weight of beef cattle are not updated regularly and the digestibility of the ration is assumed to be 65%, based on expert opinion (NIR 2014, p356). This is lower than Ireland and New Zealand who “report digestibility values of 75 and 71.4%, respectively, for non-dairy cattle in their 2011 inventory.” Webb *et al.* (2014, p356).

Figure A1 Inventory system of the European Union (European Environment Agency 2014, p4)

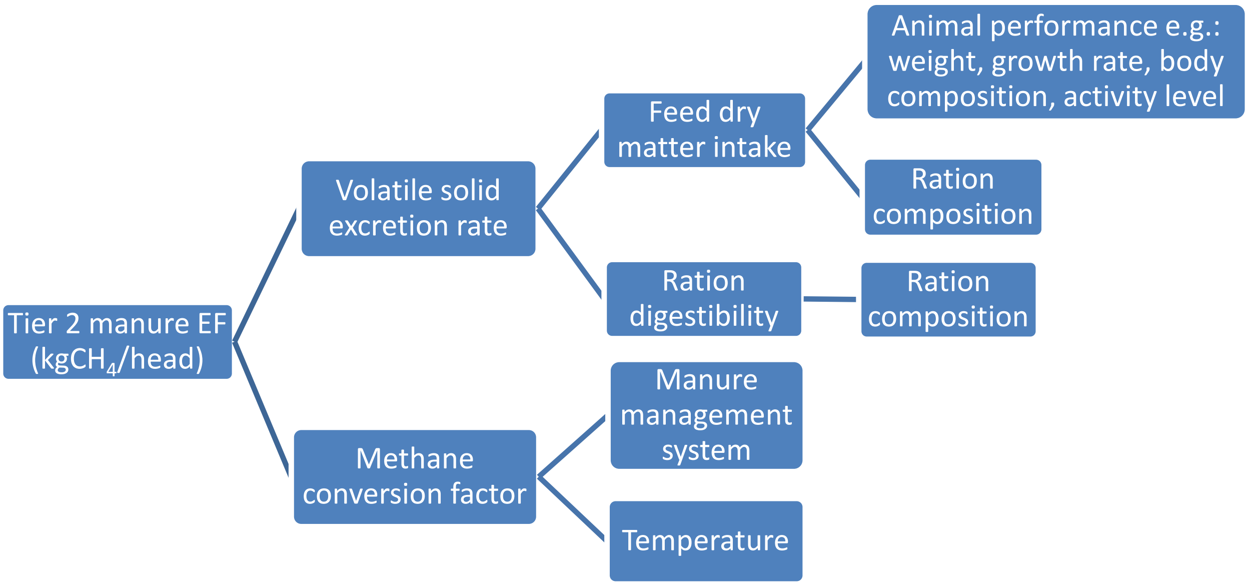


Appendix B IPCC Tier 1, 2 and 3 approaches

The difference between the Tier 1, 2 and 3 approaches depends on the emission category. In general, the Tier 1 approach involves multiplying activity data by a default emission factor (e.g. multiplying the number of dairy cattle in the UK by the Western Europe Tier 1 enteric fermentation emission factors (EF) for dairy cattle (IPCC 2006a, p10.29)), Tier 2 involves determination of the EF through a series of calculations (e.g. calculation of the dairy cow's net and gross energy requirement and feed dry matter intake based on the animal's size, milk yield, ration etc.) while Tier 3 involves the use of more complex process models. The IPCC (2006b, p4.5) recommend that Tier 2 and 3 methods are used for key categories of emissions, though where this is not possible the Tier 1 method can be used, but its use should be clearly documented.

One of the reasons why the Tier 1 approach should be seen as a last resort for some key emission categories, such as enteric CH_4 and manure CH_4 and manure N_2O, is that it employs regional default values for key parameters. These default values can obscure important differences within regions and between farm types. The Tier 2 approach (illustrated in Figure B1) means that EFs reflect differences in many parameters and therefore enable variation in these parameters to be captured. They also enable estimates to be revised in light of new evidence, for example, the assumptions about how manure is managed in the UK were revised in 2014, leading to significant changes in the manure management EFs (see Webb *et al.* 2014, p503).

Figure B1. Simplified schematic representation of the IPCC (2006a) Tier 2 approach to determining manure management methane emissions.



Appendix C. Description of key data sources

Table C1 Key data sources

Source	**Frequency**	**Parameters**
FADN	Annual.	Primarily economic data - little (no?) data on livestock or crop performance?
Farm structure survey/agricultural census	Sample survey every 2 or 3 years. Full census every 10 years.	Similar to FADN i.e. little on livestock or crop performance?
Survey on Agricultural Production Methods	One-off survey in 2010.	Some potentially useful high level data on tillage, soil conservation, grazing, housing, areas manure is applied to.
June Agricultural Census	Annual	Data on livestock numbers, distributions and stocking densities, crop areas, farm labour and rents. Section 4 of Scottish Government (2014) gives useful detail on how/why the ag census data is collected.
NIRs	Annual	Contain many useful livestock parameters (e.g. weights, excretion rates) but these are based on national statistics, and the same parameter may have different definition or mode of derivation in different countries.
CAPRI	Ad hoc updating?	Appears to be fairly crude livestock assumptions, e.g. assumes a constant weight of 600kg for dairy cows.
British Survey of Fertiliser Practice	Annual	Survey of N, P and K use in mainland Britain.

Table C2. Methodological guidance for LCA and GHG in the agricultural supply chain

Methodological guidance	
Name	Description
Livestock Environmental Assessment and Performance (LEAP) Partnership http://www.fao.org/partnerships/leap/en/	LEAP is a multi-stakeholder partnership which develops comprehensive guidance and methodologies for understanding the environmental performance of livestock supply chains.
Guidelines for National Greenhouse Gas Inventories http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html	Volume 4 of the IPCC guidelines provide methods for quantifying the GHG emissions arising from Agriculture, Forestry and Other Land Use
Greenhouse Gas Protocol http://www.ghgprotocol.org/	The Greenhouse Gas Protocol (GHG Protocol) is a widely used international accounting tool for greenhouse gas emissions, developed by the World Resources Institute and the World Business Council for Sustainable Development.
European Food Sustainable Consumption and Production Round Table (EFSCPRT) http://www.food-scp.eu/	This is an initiative, co-chaired by the European Commission and food supply chain partners, which aims to establish the food chain as a major contributor towards sustainable consumption and production in Europe. Produced the ENVIFOOD Protocol in 2012.
European Platform on LCA http://eplca.jrc.ec.europa.eu/	This European Commission platform supports business and government needs for the availability, inter-operability, and quality of life cycle data and studies
UNEP/SETAC Life Cycle Initiative http://www.lifecycleinitiative.org/	UNEP/SETAC launched the initiative in 2002 to enable users around the world to put life cycle thinking into effective practice.

Table C3. Data and tools for food LCA and GHG in food supply chains

Name	Description
Ecoinvent, GaBi, SimaPro	Commercially available LCA tools,
AGRIBALYSE	AGRIBALYSE is a Life Cycle Inventory (LCI) database for main French agricultural products (at the farm gate), following a homogeneous methodology shared between agricultural partners.
FAOstat http://faostat3.fao.org/home/E	UN FAO's database, containing global datasets on a range of relevant parameters on food production, prices, trade, food balances, inputs etc.
Eurostat http://ec.europa.eu/eurostat/web/agriculture/data/main-tables	Provides a range of agricultural production data for EU member states.
OECD.stat http://stats.oecd.org/	Provides data for a range of agricultural and environmental parameters within OECD countries.
FertiStat http://www.fao.org/ag/agp/fertistat/	UN FAO's database of fertilize use statistics
Aquaculture Feed and Fertilizer Resources Information System (AFFRIS) http://www.fao.org/fishery/affris/affris-home/en/	UN FAO's database intended to provide information on aquaculture feed and nutrient resources and guidelines to use the information on the feeding strategy.
FeedPrint http://webapplicaties.wur.nl/software/feedprint/	FeedPrint calculates the carbon footprint of feed raw materials during their complete life cycle.
Feedipedia http://www.feedipedia.org/	Feedipedia is an open access information system on animal feed resources that provides information on nature, occurrence, chemical composition, nutritional value and safe use of nearly 1400 worldwide livestock feeds.

Table C4 Farm Structure Survey data availability
http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Farm_structure_survey_(FSS)

Table 1 - Online data available for Farm Structure Survey by country

		2010	2007	2005	2003	2000	1997	1995	1993	1990
Belgique/België	BE	AC	AC	AC	AC	AC	AC	AC	AC	AC
Bulgarija	BG	AC	SS	SS	AC					
Ceská republika	CZ	AC	SS	SS	SS					
Danmark	DK	AC	SS	SS	SS	AC	SS	SS	SS	SS (1989)
Deutschland	DE	AC	SS	SS	SS	AC				
Eesti	EE	AC	SS	SS	SS					
Éire/Ireland	IE	AC	SS	SS	SS	AC	SS	SS	SS	AC (1991)
Elláda	EL	AC	SS	SS	SS	AC	SS	SS	SS	AC (1991)
España	ES	AC	SS	SS	SS	AC	SS	SS	SS	AC (1989)
France	FR	AC	SS	SS	SS	AC	SS	SS	SS	SS (AC 1988)
Italia	IT	AC	SS	SS	SS	AC	SS	SS	SS	AC
Kypros / Kibris	CY	AC	SS	SS	AC					
Latvija	LV	AC	SS	SS	SS	AC (2001)				
Lietuva	LT	AC	SS	SS	AC					
Luxembourg	LU	AC	AC	AC	AC	AC (1999)	AC	AC	AC	AC (1989)
Magyarország	HU	AC	SS	SS	SS	AC				
Malta	MT	AC	SS	SS	SS					
Nederland	NL	AC	AC	AC	AC	AC (1999)	AC	AC	AC	SS
Österreich	AT	AC	SS	SS	SS	AC (1999)	SS	AC		
Polska	PL	AC	SS	SS	AC (2002)					
Portugal	PT	AC	SS	SS	SS	AC	SS	SS	SS	AC (1989)
România	RO	AC	SS	SS	AC (2002)					
Slovenija	SI	AC	SS	SS	SS	AC				
Slovensko	SK	AC	SS	SS	SS	AC (2001)				
Suomi/Finland	FI	AC	AC	AC	AC	AC	SS	SS		
Sverige	SE	AC	AC	AC	AC	AC (1999)	SS	SS		
United Kingdom	UK	AC	AC	AC	AC	AC	AC	SS	SS	SS
Norge	NO	AC	AC	AC	AC	AC (1999)				
Schweiz	CH	AC	AC	AC						
Croatia	HR	SS	SS							
Montenegro	ME	AC								

SS Sample Survey
AC Agriculture Census
Some countries conducted the survey a year earlier or later than the standard survey period.
This is indicated above by showing the actual year in brackets.

Appendix D. Example of studies of livestock GHG emissions undertaken since 2004

Study	Country	Cattle						Chickens	
		Beef	Dairy	Sheep	Goats	Buffalo	Pigs	Meat	Eggs
Basset-Mens *et al.* (2004)	France						x		
Cederberg and Flysjo (2004)	Sweden						x		
Casey and Holden (2005)	Ireland		x						
Eriksson *et al.* (2005)	Sweden						x		
Casey & Holden (2006)	Ireland	x							
Williams *et al.* (2006)	United Kingdom	x	x	x			x	x	x
Mollenhorst *et al.* (2006)	Netherlands								x
Ogino *et al.* (2007)	Japan	x							
Dalgaard (2007)	Denmark						x		
Pelletier (2008)	USA							x	
Thomassen *et al.* (2008)	The Netherlands		x						
Dekker *et al.* (2008)	Netherlands								x
Vergé *et al.* (2009b)	Canada								x
Cederberg *et al.* (2009)	Sweden	x					x		x
Kool *et al.* (2009)	Denmark, England, Germany, Netherlands						x		
Verge *et al.* (2009a)	Canada						x		
Beauchemin *et al.* (2010)	Canada	x							
Prudencio da Silva *et al.* (2010)	Brazil, France							x	
Ripoli-Bosch *et al.* (2010)	Spain			x					
Halberg *et al.* (2010)	Denmark						x		
Pelletier *et al.* (2010)	USA						x		
Wiedemann *et al.* (2010)	Australia						x		
Foley *et al.* (2011)	Ireland	x							
Nielsen *et al.* (2011)	Denmark							x	
Lesschen *et al.* (2011)	EU27	x	x				x	x	x
Weiss and Leip (2011)	EU27	x	x	x			x	x	x
Flysjo *et al.* (2011)	New Zealand, Sweden		x						
Hagemann *et al.* (2011)	Global		x						
Henricksson *et al.* (2011)	Sweden		x						
Kristensen *et al.* (2011)	Denmark		x						
Ledgard *et al.* (2011)	New Zealand			x					
Wiedemann & McGahan (2011)	Australia								x
Thoma *et al.* (2011)	USA						x		
Leinonen *et al.* (2012a)	United Kingdom							x	
Wiedemann *et al.* (2012)	Australia							x	
Chayer *et al.* (2012)	Canada		x						
Christie *et al.* (2011)	Australia		x						
Leinonen *et al.* (2012b)	United Kingdom								x
Opio *et al.* (2013)	Global	x	x	x	x	x			
MacLeod *et al.* (2013)	Global						x	x	x
Thoma *et al.* (2013)	USA		x						
Jones *et al.* (2014)	UK			x					

Appendix E. The Global Livestock Environmental Assessment Model (GLEAM)

http://www.fao.org/gleam/en/

A significant recent initiative has been the development of the *Global Livestock Environmental Assessment Model (GLEAM).* It has been developed by the UN FAO who describe the model thus (FAO 2015a):

"GLEAM is a modelling framework that simulates the interaction of activities and processes involved in livestock production and the environment. The model is developed to assess livestock's impacts, adaptation and mitigation options at (sub)national, regional and global scale. GLEAM differentiates key stages along livestock supply chains such as feed production, processing and transport; herd dynamics, animal feeding and manure management; and animal products processing and transport. The model captures the specific impacts of each stage, offering a comprehensive and disaggregated picture of livestock production negative side effects and valuable information for intervention."

GLEAM is comprehensive in scope and uses geo-referenced information for computation. Geography is highly important to the assessment of agro-ecological processes, which depend on factors such as soil quality, climate and land use that have contrasting spatial patterns. This methodological development is a major improvement on other global assessments, which typically rely on national averages, and the GIS platform provides flexibility in combining datasets and aggregating results. GLEAM can also compensate for the shortage of global datasets on animal production and related resource use by enabling livestock statistics to be disaggregated into different systems and animal cohorts, and enabling the determination of feed rations where no datasets are available. Furthermore, GLEAM allows a wide range of parameters to be varied, thus enabling predictive modelling and design of mitigation interventions.

To date GLEAM has been used to undertake a variety of different tasks (see FAO 2015b). These include both descriptive modelling (such as the global LCA's of livestock GHG emissions, reported in MacLeod *et al.* (2013) and Opio *et al.* (2013)) and predictive modelling to, for example, estimate the effects of using sexed semen in UK dairy herds (Eory *et al.* 2014b) or treating trypanosomosis in East Africa cattle (MacLeod et al. submitted).

Appendix F. Screenshots of the xl version of GLEAM that is currently being tested

Figure F1 Input sheet for herd parameters

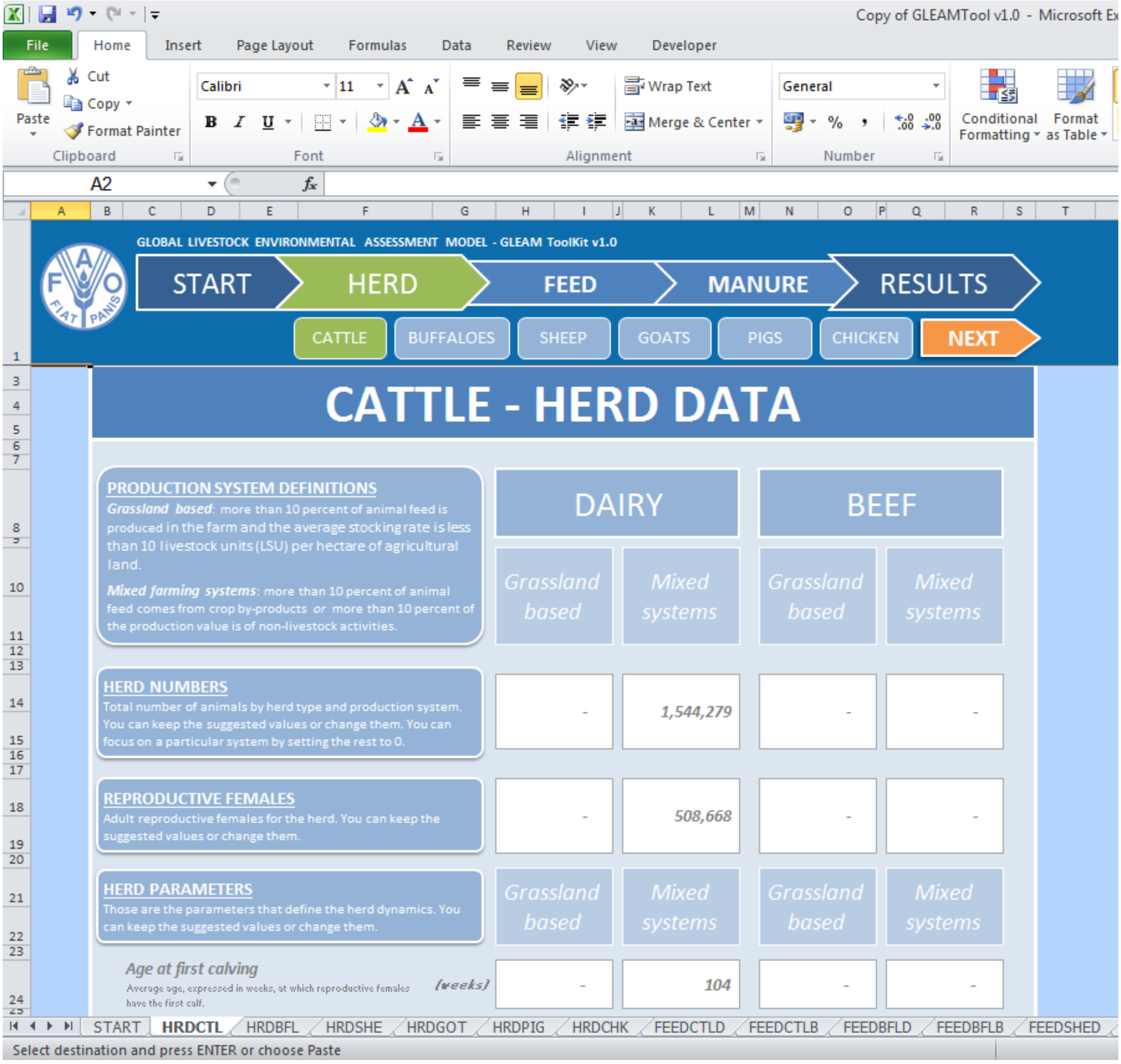


Figure F2. Input sheet for specifying the ration

DETAILED RATION - GRASSLAND SYSTEMS

DETAILED RATION - Grassland systems
The list on the right displays the individual components of the animal diet. Each item is expressed in terms of its percentage over the ration´s total dry matter intake.

SUMMARY RATION

		Grassland based systems		
		Adult females	Adult males and replacement animals	Fattening animals
Fresh grass Any type of natural or cultivated grass that is consumed fresh by the animals.	(%)	31.5	38.9	22.2
Hay or silage from grass Hay or silage from any type of natural or cultivated grass.	(%)	13.5	16.7	9.5
Fresh mixture of grass and legumes Mixture of any type of grass and leguminous plants that is consumed fresh by the animals.	(%)	3.5	4.3	2.5
Hay or silage from grass and legumes Hay or silage from the mixture of grass and leguminous plants.	(%)	1.5	1.9	1.1
Hay or silage from alfalfa (lucerne) Hay or silage from alfalfa (*Medicago sativa*).	(%)	-	-	-
Silage from whole grain plants Silage from wheat, barley, sorghum, rye or oats plants.	(%)	-	-	-
Silage from whole maize plant Silage from entire plants of maize (*Zea mays*).	(%)	21.0	25.9	14.8
Crop residues from wheat Residual plant material (straw, brans, leaves, etc.) from wheat cultivation.	(%)	3.0	3.7	2.1
Crop residues from maize Residual plant material (straw, brans, leaves, etc.) from maize cultivation.	(%)	-	-	-
Crop residues from millet Residual plant material (straw, brans, leaves, etc.) from millet cultivation.	(%)	-	-	-
Crop residues from sorghum Residual plant material (straw, brans, leaves, etc.) from sorghum cultivation.	(%)	-	-	-
Crop residues from rice Residual plant material (straw, brans, leaves, etc.) from rice cultivation.	(%)	-	-	-
Crop residues from other grains Residual plant material (straw, brans, leaves, etc.) from barley, oats or rye cultivation.	(%)	-	-	-
Crop residues from sugarcane Residual plant material (straw, brans, leaves, etc.) from sugarcane cultivation.	(%)	-	-	-
Fodder beet Fodder beet (*Beta vulgaris*) used as feed.	(%)	1.0	1.2	0.7
Maize Grains from maize *(Mea zays)* .	(%)	3.8	-	8.6
Grains Grain from wheat *(Triticum)* , barley *(Hordeum)* , oat *(Avena)* , rye *(Secale)* or sorghum *(Sorghum)* .	(%)	7.6	-	17.2
By-products from soy By-products from soy oil production, commonly referred to as 'soy cakes'.	(%)	2.3	-	5.2

Figure F3. Input sheet for manure management parameters

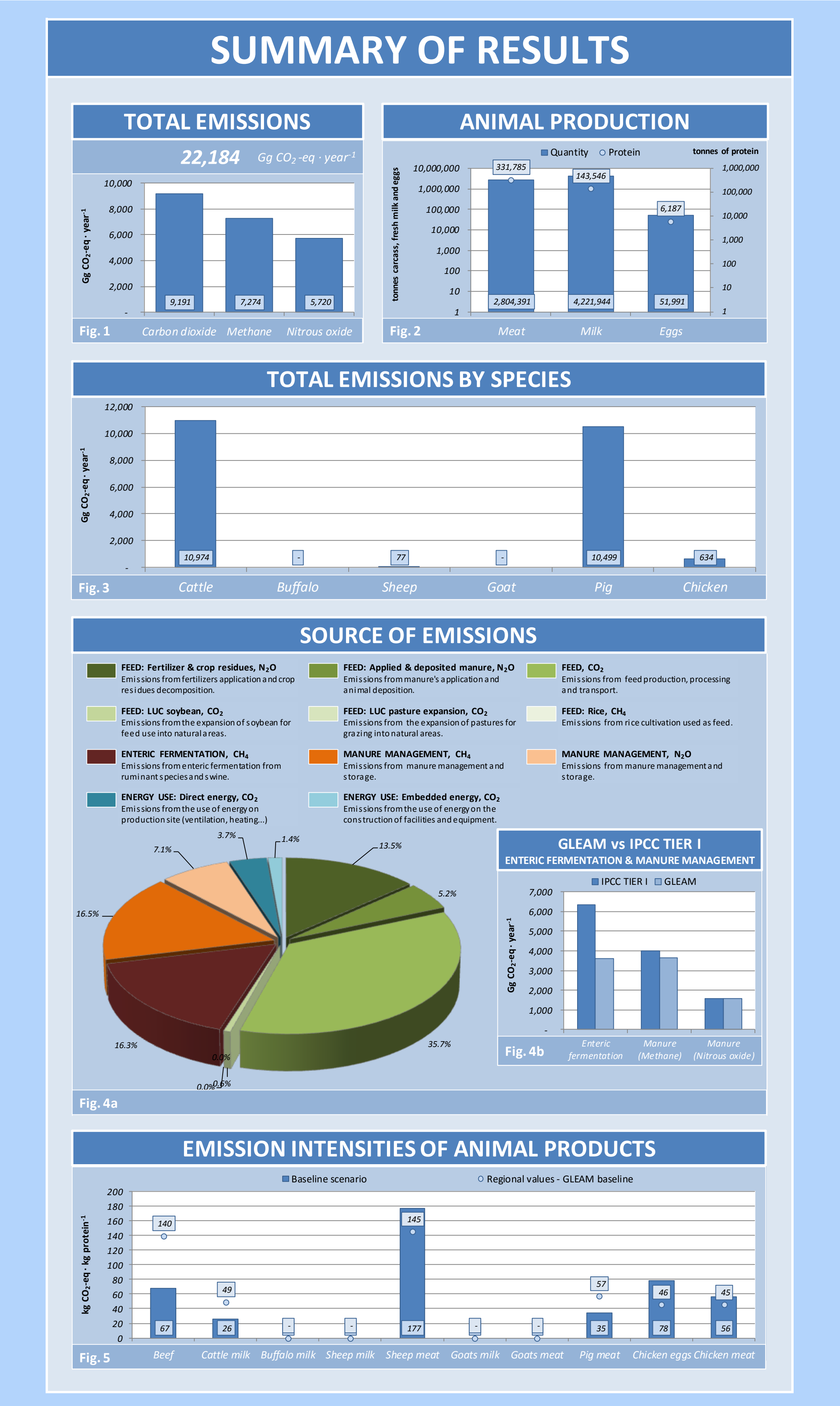
CATTLE - MANURE MANAGEMENT

MANURE MANAGEMENT SYSTEMS

Manure management systems: represent the different options for manure storage and handling as defined by the IPCC Guidelines. In this screen, you can vary the values according to the percentage of manure managed under each system.

		DAIRY		BEEF	
		Grassland based	*Mixed systems*	*Grassland based*	*Mixed systems*
Pasture/Range/Paddock Manure from grazing and scavenging animals is allowed to lie as deposited, and is not managed.	(%)	-	5	-	-
Daily spread Manure is routinely removed from a confinement facility and is applied within 24 hours of excretion.	(%)	-	-	-	-
Solid storage Manure is stored usually for some months in unconfined piles or stacks with sufficient amount of bedding material or humidity loss.	(%)	-	9	-	-
Dry lot Manure is accumulated within an open confinement area without significant vegetative cover. Manure may be removed periodically.	(%)	-	-	-	-
Liquid/Slurry Manure is stored as excreted in tanks or earthen ponds outside the animal housing, usually for periods less than a year.	(%)	-	86	-	-
Uncovered anerobic lagoon Liquid storage system that combines waste stabilization and storage. The water can be recycled as flush water or for irrigation.	(%)	-	-	-	-
Burned for fuel The dung and urine are excreted in the fields. The sun dried dung cakes are burned for fuel.	(%)	-	-	-	-

Figure F4. One of the results sheets



Appendix G Input data required and availability

Herd parameters

Parameters defining the individual animal's performance, and enabling the determination (if required, see above) of the herd structure. NIRs provide regularly updated data (for Annex 1 countries, see Appendix A) for dairy cattle weights and milk yields. NIR data for beef cattle and sheep weights are limited, but should be obtainable for EU countries from other sources, e.g. DG Agri (2013b), or the Farm Accountancy Data Network (FADN). Data for herd rate parameters (mortality, fertility etc.) are not readily available at an EU level, but it may be possible to determine some of these from the Cattle Tracing Scheme. For Scotland, it should be possible to obtain reasonably robust values for these parameters from a combination of: QMS (2014), SAC (2015), expert opinion, and Fertbench.

Manure management parameters

Information on how manure is managed should be available in the NIRs and in Eurostat. Data on rates of manure application are available for the UK in the British Survey of Fertiliser Practice (BSFP). It should be possible to calculate average manure application rates if stocking rates are known, though this is not straightforward. Some information on modes of manure application to land is available in Eurostat.

Feed parameters

Ration nutritional value is of central importance to the calculation of EI. The digestible energy (DE) content directly affects the rates of enteric methane emission. Ration DE and N content also influence the rate at which volatile solids (VS) and nitrogen are excreted, and the consequent CH_4 and N_2O emissions from manure management. Some information on rations is available in the NIRs, though given the importance of the ration nutritional values, these should be validated.

Robust data should be sought on the nutritional values for key feeds, i.e. those that form a significant % of the ration and whose nutritional value may vary between countries, such as pasture, silage and hay. It should be noted that in UK NIR (Webb *et al.* 2014, p663, p355) the forage DE is based on data from 1990. It may be worth checking if this is this still applicable given the importance of this parameter.

The calculation of N_2O and CO_2 arising during crop production should, in theory, take into account differences between countries that are likely to influence the crop EI, e.g. differences in nutrient use efficiency, use of zero tillage systems, use of legumes, use of precision farming techniques, use of low emissions fuels. In practice a relatively simple tier 1 approach to determining crop emissions that focuses on a small number of key differences (e.g. land use change arising from imported soy and use of legumes) may be more appropriate, given (a) the lack of data to perform more complex calculations, and (b) that a significant amount of feed is imported. Emission factors can be derived from databases (such as FeedPrint) for selected non-crop feed materials.

On-farm energy use

Emissions from on-farm energy use are likely to represent a small proportion of the total emissions for beef and sheep production, but may be significant in dairy production, depending on cooling systems used etc. Data on on-farm energy use is mainly in the form of one-off studies (e.g. Defra (2007), AEA/ FEC Services Ltd (2010), Domingo *et al.* (2014), European Commission Joint Research Centre (2015)); limited recurring data is available in Eurostat (2015).

Post-farm processes

Emissions arise post-farm during transportation, processing, retail, consumption and disposal. Most of the emissions are in the form of CO_2 arising from energy use, though there are also emissions from refrigerant use and CH_4 from waste disposal. Post-farm emissions are a relatively small proportion of the emissions for beef and milk (see Figure 2). However, the EI is a function of both the emissions *and* the amount of product at a particular stage. So for products, such as liquid milk, that have high post-farm losses, the EI can increase significantly post-farm, even if the post-farm emissions are relatively small. A decision and therefor needs to be made on where the system boundaries lie, and the functional unit the EI is to be expressed in (e.g. kg CO_2e/kgLW_at farm_gate or kgCO_2e/kg_bone_free_meat_at_retail_point) bearing in mind the challenges of obtaining robust data on post-farm emissions and losses.

Allocation

Wool values are required to allocate sheep emissions between meat and fibre in the calculation of sheepmeat EI. If meat EI is to be expressed in terms of carcass weight or bone-free meat then information on the value of slaughter by-products is required. It is unlikely that robust country-specific data will be available on this, however this only matters if there are significant differences between countries in the value of the slaughter by-products (which is unlikely within the EU given the consistency of EU law on the use of by-products).

The economic (and nutritional) values of some crop by-products are important, particularly for beef, where by-products (of brewing and distilling) are commonly used. The economic values of some wastes (e.g. cakes, broken biscuits from the food industry) may be required if they are used in significant amounts as feeds.

Other

In order to distinguish between countries, cultivation differences that would affect crop EI should, as far as possible, be taken into account , e.g. % of organic v conventional, use of legumes, use of nitrification inhibitors, zero tillage, precision-farming techniques, cover crops etc. Similarly, for livestock production, distinctions should be made between the main systems and their characteristics, e.g. dairy beef v suckler beef, grazing v feedlot, organic v conventional.