Technical Annex: The Smart Agriculture Inventory

Acknowledgements

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A number of stakeholders for their contribution including Steven Anthony at ADAS, Tom Misselbrook at Rothamsted Institute, Adrian Williams at Cranfield University and Luke Spadavecchia and Rick Bruintjes at Defra.

Technical Annex: The Smart Agriculture Inventory

Summary and key messages

The new 'smart' inventory was implemented in 2018 following the completion of an extensive seven year work programme to improve the method for estimating non-CO₂ emissions in UK agriculture. This technical annex sets out the main improvements made to the methodology, the research work that underpins the new emissions estimates, and the implications of the new estimates for agriculture emissions and the ability of the Committee to monitor and evaluate the sector's progress in reducing emissions.

The key messages are:

- The Committee welcomes the new agriculture inventory and recognises the wide body of research underpinning it. It enables closer monitoring of emissions sources and trends and has the potential to enable improved exploration of mitigation measures.
- The vast majority (over 80%) of agriculture emissions are now estimated by UK specific emission factors and activity data.
- Overall UK agricultural emissions have been revised downwards by around 15% compared to estimates using the previous methodology (a change of 8.2 MtCO₂e in 2013 estimated emissions). The trend is broadly unchanged with emissions falling by almost a fifth since 1990.
- The largest revisions have been to Nitrous oxide (N₂O) emissions from soils, the estimate for which reduced by around one-third in 2013. The revision to methane emissions was much lower, at 4.7%, with a decrease in estimated emissions from enteric fermentation partially offset by a rise in emissions from waste management.
- Field experimentation and extensive trials have allowed a much greater level of disaggregation that better reflects UK-specific spatial and temporal conditions and factors.
- Methane emissions from enteric fermentation from cattle and sheep are now highly disaggregated by age, diet, production system, and breed. The research found that diet is more important than other factors such as breed.
- There is much more detailed disaggregation of soil emissions, with fertiliser emissions varying by soil type, rainfall and application practice. This has led to more variation in fertiliser emission factors by devolved administration.
- Going forward a fuller representation of mitigation practices would help to explore the impact of different mitigation measures.

We set out our analysis in the following sections:

- 1. Background and context
- 2. Emissions from agricultural soils
- 3. Emissions from livestock
- 4. Conclusions

1. Background and context

In previous reports, the Committee has highlighted the uncertainty underlying the agriculture Greenhouse Gas (GHG) inventory and the difficulty that this presents in both identifying mitigation potential and monitoring and evaluating progress to meeting carbon budgets. The approach used to estimate GHG emissions combines information on the extent of the activity being assessed with an emissions factor that reflects the emissions per unit of the activity. The basic equation is:

*Emissions = activity data * emissions factor*

Emissions estimates using this method are classified according to Tiers (1, 2 or 3), which reflect the complexity of the methodology. In general, higher Tier methods are considered to be more accurate as they use country-specific data that are more likely to be representative of local conditions. In contrast Tier 1, the most basic method, is designed to use readily available national or international statistics in combination with default emission factors and other parameters provided by IPCC that are unlikely to reflect local conditions.

Historically (up to the 2015 UK GHG Inventory¹), estimates of agricultural non-CO₂ emissions have been calculated using mainly a mixture of Tier 1 and Tier 2 methodologies. Under the 2015 GHG inventory, the Tier 1 approach accounted for 40% of UK agricultural emissions, and all the N₂O emissions from agricultural soils used default emission factors. Therefore a high proportion of estimates used non-UK specific data. In contrast, CO₂ estimates have always been calculated on the basis of a Tier 3 approach due to energy combustion being the dominant source of CO₂ (Box 1).

Box 1. Previous methodology used for estimating agricultural non-CO₂ emissions

In agriculture, estimates of non-CO $_2$ emissions have previously been calculated using mainly a mixture of Tier 1 and Tier 2 methodologies:

- Agricultural soils give rise to N₂O emissions, and under the old methodology were mainly calculated based on the quantity of nitrogen fertiliser applied (both synthetic and organic) and the quantity of agricultural lands to which it was applied. Emissions factors were entirely based on default emission factors using IPCC Tier 1 methodologies and as such did not reflect UK climatic or soil conditions, nor the latest agricultural practices.
- Emissions from enteric fermentation were estimated by multiplying livestock numbers with the relevant emissions factor. Beef and dairy cattle had been based on UK specific factors, using country specific data such as live weight, milk yield, feed digestibility and carcase weight for beef cattle to generate Tier 2 emissions factors. All other livestock types used default IPCC (2006) Tier 1 factors, which did not change from year to year.
- Methane and N₂O emissions due to waste and manure management were calculated using Tier 2 country specific emissions factors. There are different emissions factors depending on the livestock type and manure management system used (e.g. liquid system and daily spread).

Data was taken from a range of sources, with some of the main ones being:

• Defra's June Survey of Agriculture and Horticulture provides data on crop areas and livestock numbers used to derive estimates of emissions from the large sources, such as enteric fermentation, animal wastes and manure management, and soil emissions. In addition, Defra's annual publication, the British Survey of Fertiliser Practice is used to derive the soil emissions arising from the use of organic and chemical fertiliser.

¹ DECC (2015), UK Greenhouse Gas Inventory, 1990 to 2013.

The use of IPCC default emission factors under the Tier 1 approach gave rise to a high degree of uncertainty in estimating UK agricultural emissions and the impact of UK-specific farming practices:

- **Uncertainty in measuring emissions.** The estimation methodology, which largely applies default emissions factors to fertiliser application and the population of certain livestock types meant that a host of factors that can influence UK emissions were not taken into account in estimates. This included differences in soil type and soil moisture, animal feed type and fertiliser type.
- **Uncertainty in current farming practices.** As default emission factors do not reflect UK farming practices it followed that there was a high degree of uncertainty over the extent to which the deployment of alternative agricultural practices over time would reduce emissions.

The combination of these uncertainties meant that the level of agricultural emissions could be very different from what was being reported. For example, the uncertainty in the 2015 GHG inventory was 36% (with 95% confidence) than the reported 2013 level.

This uncertainty in measuring emissions and not being able to reflect the impact of farming practices made it difficult to accurately assess the progress in reducing emissions and the contribution to meeting carbon budgets.

Defra and the devolved administrations (DAs) recognised the need to improve the methodology for estimating agricultural emissions, and funded the Agricultural Greenhouse Gas Research Platform. This was an extensive research programme to improve the calculation of non-CO₂ emissions, with the explicit aim to develop a fully revised agricultural inventory. In recent progress reports to Parliament, the Committee has recommended the completion of the new inventory methodology to allow more accurate monitoring of agriculture emissions. The publication of this work is therefore welcome.

Overview of the Agricultural Greenhouse Gas Research Platform

The Agriculture GHG research platform was a seven year programme undertaken by a multidisciplinary consortium of around twenty leading academic and research bodies, in joint collaboration with Defra and the DAs². Through the use of field trials and experiments, data mining and modelling, the research sought to better understand and measure how biological systems and different farming practices impact on emissions. This involved taking a more disaggregated approach to improve both spatial and temporal resolutions, which would allow for the reporting of emissions for different agricultural regions and seasons.

The two main projects from the GHG Platform focused on developing emission factors for the main sources of methane and N_2O :

• Methane emissions project (ACO115) aimed to deliver a set of revised methane emissions factors, from a range of appropriate cattle and sheep breeds and associated management practices to deliver more spatially and temporally disaggregated estimates of methane emissions. The project evaluated different tools to assess methane outputs from livestock such as trace gas measurements, respiration chambers and more experimental approaches such as laser methane detectors. There were also improvements in the sampling fraction of the activity data used to estimate livestock numbers which increased the sample size of some surveys and should help to improve accuracy.

² See http://www.ghgplatform.org.uk/ for a full list of research partners

• N₂O emissions project (ACO116) aimed to improve N₂O emissions factors from soils to better reflect the effects of different soil types, climatic zones, farming systems and nitrogen management. N₂O was measured using a standard experimental protocol combining static and automatic chamber³ methodologies alongside ammonia gas sampling, nitrate leaching samples, and soil analysis to provide clarity on the pathways and magnitude of nitrogen losses in typical UK agricultural systems. It also investigated the relationship between fertiliser nitrogen application rate and N₂O emissions as there was growing evidence that it was non-linear.

The projects also drew on other evidence and research to develop the new inventory estimates.⁴ The next sections set out the key methodological changes and how these have impacted on the level and trend in methane and N_2O emissions estimates.

2. Emissions from agricultural soils

In 2016, N₂O from soils accounted for 11 MtCO₂e, or 24% of agriculture emissions. The main sources of N₂O emissions are inorganic fertiliser application, grazing returns, crop residues and manure application, which together account for 84% of N₂O emissions from soils (Figure A1).



The 'smart' inventory estimates are based on targeted field-scale trials - designed to fill gaps in the existing data set - which were conducted following the application of inorganic fertiliser, manure and urine on nine experimental sites across the UK comprising four arable and five grassland systems. The experimental sites selected were representative of different soil types

 $^{^{3}}$ Chambers are open-bottomed devices that are placed on the soil to measure $N_{2}O$ fluxes from soils.

⁴ For example, the MIN-NO project (2009 to 2014) used multi-site industry data, field experiments and modelling to improve estimates of N₂O emissions associated with major UK arable crops.

(e.g. sandy, clay), and annual cumulative rainfall in order to better understand the spatial resolution of emissions across the UK. 37 plot-scale experiments were conducted to generate N₂O emissions using static chambers. The National Physical Laboratory (NPL) worked with the experimental team to ensure measurements were consistent and comparable across the UK. These experiments were augmented with UK data from other projects (e.g. MinNO) that met strict quality criteria set out by the IPCC.

The key changes to the estimation of soil based emissions are in the four largest sources of N_2O emissions: inorganic fertiliser, manure application, grazing returns and crop residues.

- **Inorganic fertiliser** emission factors are now spatially disaggregated on a 10 km² basis according to fertiliser type (i.e. urea and ammonium nitrate), and reflect regional variation in fertiliser application rates and rainfall (Figure A2):
 - Fertiliser application rates vary with farm system type, such as lowland cropping and upland grazing, whose regional distribution reflects long-term soil and climate constraints.
 - Rainfall amount is also an indicator of soil wetness and aeration that regulate N₂O emissions. For example, wetter regions of the country such as the South West of England, will tend to have a higher ammonium nitrate emission factor, all other things being equal, compared to East Anglia which receives less rainfall.

The studies found a non-linear relationship between average annual rainfall and the emission factor for applying ammonium nitrate (Figure A3). Crop type or soil organic matter were found not have significant effects on their own. For urea fertiliser, the trial data was not able to establish a statistical relationship between rainfall and its application, and thus in the updated inventory model emissions from urea use is only responsive to the amount applied (Figure A4).

- **Application of livestock manure** emission factors are now disaggregated by manure type, with liquid slurries having a higher emission factor (0.75% of total nitrogen applied) than the use of farm yard manure (0.36%) due to higher nitrogen availability. However a lack of data means that emissions factors could not be disaggregated between the use of manure by land type (l.e. grassland and arable). In addition, the emission factors are not spatially or temporally disaggregated.
- Livestock grazing returns are estimated using separate emission factors for cattle dung (0.19% of total nitrogen applied) and urine (0.63%) deposited on grassland. In the absence of any experiments being conducted on sheep, the same emission factors are applied to sheep grazing returns as for cattle. Estimates of nitrogen excretion by livestock are based on the use of UK-specific metabolisable energy balance equations and reflect diet characteristics.
- **Crop residue** emissions are now estimated with country specific data for activity, using the harvest index for arable crops to derive the quantity of residues and the nitrogen content of the residues. A default emission factor is then applied to these.

The new inventory also includes a limited range of management practices which could reduce N₂O emissions. These include the use of clover crops on grassland, which fix nitrogen, thereby offsetting the use of fertiliser, and how fertiliser is applied and incorporated into soils. It also covers a range of techniques for applying manure on land that can reduce emissions. These include low trajectory band spreaders for applying slurry and direct injection. While these are welcome, there are still some gaps in the inventory regarding the representation of a wider range of mitigation practices on soils such as the impact of cover crops.





Figure A3. Emission factors for a range of ammonium nitrate fertiliser inputs at a range of annual rainfalls (% of total N applied)



Impact of the new inventory on agricultural soil emissions

The implementation of the new inventory has led to a large downward revision in the absolute level of emissions across the time series since 1990. The overall trend in emissions is broadly unchanged. Comparing the 2015 inventory with the latest 2018 inventory which incorporates all the improvements shows (A5):

- N₂O emissions from soils are now on average 40% lower across each year of the time series.
- N₂O emissions from soils now account for around a quarter of all agricultural emissions, compared with 36% under the previous methodology.
- Grazing returns accounted for the largest change in emissions between the two methodologies both in absolute terms and in percentage terms, down 4.7 MtCO₂e (81%) for 2013 estimated emissions. Estimated emissions from the use of inorganic fertiliser are now a third lower and 12% lower for manure application.

The updated country specific methodology now covers 84% of N₂O emissions from soils, with the remaining 16% based on IPCC default emission factors.



3. Emissions from livestock

In 2018 livestock emissions were 29.1 MtCO₂e representing 63% of all agricultural GHG emissions⁵. These are mainly methane emissions from enteric fermentation (21.9 MtCO₂e) and from the management of waste and manure (7.2 MtCO₂e), of which 60% is methane and 40% N₂O. Ruminant livestock (cattle and sheep) comprise the majority of these emissions (92%) (Figure A6).

⁵ These figures exclude soils emissions arising from livestock sources such as manure application and grazing returns as these are covered in Section 2.



The main improvements to estimates of livestock emissions were from ruminant animals as these account for most of the emissions from enteric fermentation. Revisions were also made to estimates of waste and manure management for pigs and poultry.

Across the livestock sector, a refined categorisation of farming systems has been implemented to better reflect UK practices. For cattle and sheep, the improvements focused on developing a set of revised country specific emission factors for the key emission sources, as there are already good sources of information on the number, age and breed of livestock in the UK. The aim of the improvements was to deliver a revised set of emission factors for cattle and sheep and to produce spatially and temporally disaggregated emissions estimates.

The research investigated the extent to which differences in breeds, genetics, age, size and diets, and farming systems impact emissions. Field trial data were collected using eight different breeds of sheep and eight breeds of cattle; seven different forage types for sheep and 11 for cattle. A range of representative UK production systems comprising both in-door housing and outdoor grazing provided an understanding of how emissions can vary spatially and temporally.

Enteric fermentation

Measuring enteric methane from animals is difficult and the project used two main techniques. Respiration chambers were used for livestock housed indoors, whilst the Sulphur-Hexafluoride tracer technique was used for animals at pasture. The NPL worked with the experimental team to ensure measurements were consistent and comparable across the UK.

Methane emissions are essentially a function of dry matter intake (DMI) by livestock. DMI is the amount of feed an animal consumes per day on a moisture-free basis, and is determined by the energy available to the animal through food after accounting for losses in digestion, gases and

urine (the metabolisable energy (ME)). The research estimated the relationship between DMI and enteric emissions based on the latest scientific information on how much energy is needed for livestock weight gain and other livestock outputs (e.g. milk). The shape of this function was modelled using data from the field experimentation and trials. This established UK-specific energy-balance equations based on metabolisable energy, which were previously based on IPCC default equations.

The emissions factors resulting from this project are now much more disaggregated:

- By age and breed. Four age categories were used for dairy cattle, 15 for beef. Three production intensity categories were used to represent dairy milk yields. For beef, four breed types and six sub-categories to categorise roles were used (e.g. beef cows, beef heifers for breeding, breeding bulls, steers for slaughter etc.)
- By production system used for cattle and sheep. For example, sheep emissions factors were estimated for three production systems: upland, lowland, and hill breeding system based on holding location.
- Diet characterisation is now based on estimates of feed intake from grazing, forage, silage and concentrates.
- Periods of indoor and outdoor housing are estimated to better represent the feeding regime.

For dairy and beef cattle there was also a move from annual (using the June agriculture survey) to monthly estimates of livestock numbers (based on the Cattle Tracing Scheme database). This resulted in much lower estimates of annual livestock numbers as June (the previous survey month) was the period with the highest number of livestock.

The project confirmed the view that feed as measured by dry matter intake is the most important driver of enteric methane emissions in cattle and sheep. Other key findings were:

- There was limited variability in emissions factors by breed type but a much greater effect of diet type where higher quality (lowland) forage produces more methane than poorer quality (upland) forages. Animals on concentrate-based diets produced less methane than those fed on high-forage diets.
- Of the ten different cattle types represented in the new inventory, dairy cows have the highest annual emissions factor for enteric fermentation, dairy calves of less than one year the lowest (Figure A7).
- Revised dairy and sheep emissions factors were lower than previous values, but for beef these increased. The trend of dairy emissions factors is upwards, reflecting higher milk yields and heavier cattle.

The impact of all the methodological changes to estimated methane emissions from enteric fermentation are:

- A downward revision of around 7-9% across all years from 1990 when comparing the 2015 and 2018 inventories. For example the estimate of 2013 enteric fermentation emissions was 23.5 MtCO₂e in the 2015 inventory and 21.5 MtCO₂e in the current inventory (Figure A9).
- This reflects lower livestock numbers and lower cattle emissions factors which offset higher dairy cattle emissions factors.
- There was a similar percentage reduction for both cattle and sheep.



Waste and manure management

In 2018 the storage and management of livestock waste produced 7.2 MtCO₂e, comprising 60% methane and 40% N_2O emissions. The key changes in the methodology to estimate these are set out below.

i) Methane emissions

Methane arises when waste, usually stored as slurry decomposes under anaerobic conditions in either a pool, lagoon or tank. In contrast, waste in its solid state and when used on land, decomposes aerobically and therefore produces little or no methane.

Emissions factors for manure management are based on an equation where emissions are a function of: volatile solids excretion, dry matter intake and feed energy content, gross energy intake and ash content of manure.

Experiments were conducted using different production systems (indoors and outdoors) and manure management types to improve estimates of methane emissions for livestock. For cattle and sheep, the emissions factors moved from using default IPCC values to UK-specific estimates based on the UK-energy balance equations noted above. For all other livestock, IPCC default values continue to be used.

These emissions factors are combined with country-specific data on different manure practices based on Defra's Farm Practices Survey. The data reflect:

• Different waste management systems emitting a different amount of methane per unit of manure, with manure managed as slurry being the highest (due to the anaerobic conditions) and daily spread of farm yard manure the lowest.

 The new inventory assumes that nearly two-thirds of the dairy cattle waste was being managed as slurry, compared to only 18% of other cattle. This large difference probably indicates that dairy cattle tend to be housed indoors for much longer than non-dairy, thereby making it easier for the waste to be collected and stored as slurry. This is supported by activity data that suggests almost 50% of non-dairy cattle manure is managed on pasture land (Figure A8).



The move to the new methodology has led to an upward revision in the level of methane emissions from waste and manure management by a fifth, from $3.5 \text{ MtCO}_2\text{e}$ in 2013 based on the 2015 inventory, to $4.2 \text{ MtCO}_2\text{e}$ in the current inventory.

This increase was offset by the much larger decrease in methane emissions from enteric fermentation as set out above. Overall methane emissions from livestock are therefore around 4-5% lower under the new inventory (Figure A9).



ii) Nitrous oxide emissions

In 2018 emissions from nitrogen excreted from livestock waste which is then converted to N_2O were 2.9 MtCO₂e. The emissions vary according to:

- The amount of nitrogen excreted per animal sub-category type, which is calculated using country specific data based on diet and production characteristics.
- The type of manure management system determines how much of that nitrogen excreted is converted to N₂O emissions. The type of manure management system is in part determined by housing type

The new inventory methodology has updated IPCC default N₂O emission factors for some waste management systems. Country-specific emission factors for cattle, sheep, pigs and poultry are now higher than previous default values. This has led to an upward revision in the emission estimates of N₂O from waste management (Figure A10):

- Total N₂O emissions from this source are around 50% higher across each year of the time series back to 1990 in the 2018 inventory compared with the 2015 submission.
- The upward revision is largely due to higher cattle waste management emissions, though there have also been increases for pigs and poultry.

Improved representation of waste management also allows for better monitoring of mitigation practices. However, only a handful of these are covered in the new inventory: storage of farm yard manure with a store cover and incineration of broiler and turkey litter.



4. Conclusions

The introduction of the 'smart' inventory means that over 80% of agriculture emissions are now estimated using UK-specific emission factors. The new inventory has led to a lower estimate of both N₂O and methane which has resulted in an overall reduction in agricultural emissions of around 15% (8.2 MtCO₂e) for 2013. The trend in emissions from 1990 is largely unchanged as revisions have been implemented across the time series (Figure A11).



The implementation of the new inventory represents a large improvement in the evidence underpinning estimates of UK agriculture emissions. There is greater confidence that the majority of estimates now reflect UK-specific conditions. Going forward key challenges for government are:

- To ensure that resources are put in place to enable full analyses of the data underlying the new inventory. This should focus on using the data to explore the potential for future mitigation, for example using scenario-based analyses.
- Ensure that the new inventory can identify and, where possible, quantify the full range of current and possible future farming and mitigation practices. Where this is not possible, to ensure that other datasets (e.g. the Farm Practices Survey) continue to collect information that will support the analysis of emissions trends.
- To ensure that the National Inventory Steering Committee's emissions improvement programme identifies areas for further exploration and improvement. This should be supported by uncertainty analysis.

The Committee will be developing a new indicator framework to monitor emissions in this sector, which will be published in the 2019 progress report.