FAPRI-UK Greenhouse Gas Emission Modelling System for England, Wales, Scotland and Northern Ireland

FAPRI-UK Project

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1. Introduction

Growing scientific consensus on the dangers and consequences of climatic change (IPCC, 2007a and 2007b) has pushed the issue of Greenhouse Gases (GHGs) up the political agenda, with world leaders meeting at the United Nations Climate Change Conference in Copenhagen in December 2009. While the resulting Copenhagen Accord (UNFCCC, 2009) was widely regarded as a failure due to the non-binding nature of the agreement, it may be used as a foundation for further UN climate change discussions. The first major international agreement to combat climate change was the Kyoto Protocol, which was agreed in 1997 and committed countries to cut emissions of four GHGs (carbon dioxide, methane, nitrous oxide, sulphur hexafluoride) with the aim of stabilising greenhouse gas concentrations in the atmosphere at a level that would prevent serious climatic change (UNFCC, 1997). Under this agreement the European Union (EU) agreed to reduce GHG emissions by 8 per cent below 1990 levels by 2012.

More recently, increased concerns about the threats posed by climate change has led to the development of more radical targets in the EU and the UK. EU leaders agreed in December 2008 to cut GHG emissions by 20 per cent below 1990 levels by 2020, or 30 per cent if a new global agreement is reached, as part of the EU Climate and Energy Package (European Council, 2008). In the UK, the 2008 Climate Change Act set substantial long-term binding targets to reduce GHGs by at least 80 per cent by 2050 compared with 1990 levels (Department of Energy and Climate Change, 2008)[1]. In the nearer term, the UK Climate Change Act requires a reduction in emissions of at least 34 per cent by 2020 (compared with 1990 levels). At the individual country level within the UK, devolved administrations have set targets to reduce GHGs in tandem with the UK Climate Change Act. The Climate Change Scotland Act 2009 set an equivalent long-term GHG reduction target for Scotland for 2050 and a more significant interim 42 per cent reduction target for 2020 (Scottish Government, 2009). In Wales, the Assembly Government committed an annual 3 per cent reduction in greenhouse gases target from 2011 onwards (Welsh Assembly Government, 2009). Within Northern Ireland, the 'Sustainable Development Strategy' specified a target to reduce GHG emissions by 25 per cent below 1990 levels by 2025 (Office of the First Minister and Deputy First Minister, 2006).

While the above policies established target reductions for GHGs for the economy as a whole, specific targets were not set for the agricultural sector. In a recent White Paper (HM Government, 2009), however, the UK Government outlined plans to meet the 34 per cent GHG emission reduction target for 2020 and specified a target to reduce GHG emissions from agriculture in England by 3 mt CO^2 equivalent a year by 2020. The plan encourages voluntary action, but a review will be undertaken in 2012 to determine whether government intervention is necessary. The Scottish Government has committed to reductions of 0.7Mt CO^2 equivalent a year by 2020 on 2006 levels (if a 34% target is accepted overall) and 1.3Mt CO^2 equivalent (if a 42% target is accepted overall). The Welsh Assembly Government proposed a reduction of 0.6Mt CO^2 equivalent a year by 2020.

[1] In March 2009, the Climate Change Act was updated to reflect the final contents of the Act (Department of Energy and Climate Change, 2009).

Agriculture generates GHG emissions from a variety of sources. In particular, the digestion process of ruminant animals (enteric fermentation), the decomposition of manure and direct/indirect emissions from agricultural soils produce two types of GHGs, namely methane (CH_4) and nitrous oxide (N_2O), which are particularly harmful in terms of global warming potential. In addition, CO_2 emissions also arise from fossil fuel consumption associated with farming (e.g. power for farm machinery and buildings) and disturbed soil due to land use change (e.g. deforestation and conversion of grassland to arable). Note, the FAPRI-UK GHG sub-model focuses on agricultural emissions of methane and nitrous oxide. This is consistent with the definition of emissions from the 'Agricultural' sector (Common Report Format (CRF) sector 4) within the official UK GHG Inventory (Jackson *et al.*, 2009). The modelling system does not currently cover emissions and removals of GHGs due to land use, land-use change and forestry activities (LULUCF i.e. CRF sector 5 within the official inventory)[2].

Using the official GHG inventory definition which focuses on methane and nitrous oxide emissions only (i.e. CRF sector 4), the agricultural sector accounted for approximately 7 per cent of total UK GHG emissions in 2007. The contribution of the agricultural sector to total GHGs varies across the UK according to the degree of agricultural activity relative to other GHG sources (industrial and energy related). In percentage terms, the agricultural sector in England contributes 5 per cent to total English GHG emissions, compared to 10 per cent in Wales, 13 per cent in Scotland and 21 per cent in Northern Ireland. While the contribution of agriculture to total GHG emissions is significantly greater in Northern Ireland compared to the other regions in the UK, it is less than the Republic of Ireland (27 per cent) reflecting the absence of heavy industry throughout the island of Ireland.

With specific regard to methane and nitrous oxide emissions from agriculture, England contributes the greatest amount to total UK GHG emissions in the agricultural sector (62 per cent in 2007), followed by Scotland (16 per cent), Wales (11 per cent) and Northern Ireland (11 per cent). Estimated total UK GHG emissions from agriculture have declined significantly in recent years. Over the period 1990-2007 (1990 being the reference year for reduction targets) total UK GHG emissions from the agriculture sector (CRF sector 4, i.e. methane and nitrous oxide emissions) fell by 20 per cent due to decreasing livestock numbers and reduced use of fertilisers. This decline is mirrored in England, Wales and Scotland (22, 19 and 21 per cent respectively). In Northern Ireland, however, GHG emissions from agriculture only fell by 8 per cent over the same period. Unlike the rest of the UK, cattle numbers in Northern Ireland did not show a downward trend over this period.

A GHG sub-model has been developed as part of the FAPRI-UK modelling system. This sub-model provides projections of methane and nitrous oxide arising from agriculture in England, Wales, Scotland and Northern Ireland for a given policy environment. The GHG sub-model is incorporated within the partial equilibrium model of UK agriculture, the main FAPRI-UK model which, in turn, is an element of the FAPRI European GOLD model. This linkage means that projections of greenhouse gases are based on projections of commodity outputs and input usage

[2] The FAPRI-UK modelling system does not specifically model the land use categories used within the LULUCF system (i.e. forest, cropland, grassland, wetlands, settlements and other land). Modelling the forestry sector in particular is problematic due to the timeframe between planting trees and realizing economic returns. Nonetheless, future development of the FAPRI-UK modelling system will incorporate the carbon stock properties of grassland and cropland.

from the main FAPRI-UK modelling system. This paper describes the methodology underlying the modelling systems and presents some initial Baseline projections of GHGs for England, Wales, Scotland and Northern Ireland.

2. Methodology

2.1 Main FAPRI-UK modelling System

The FAPRI-UK modelling system (created and maintained by personnel in AFBI-QUB) captures the dynamic interrelationships among the variables affecting supply and demand in the main agricultural sectors of England, Wales, Scotland and Northern Ireland. The model consists of a system of equations covering the dairy, beef, sheep, pigs, poultry, wheat, barley, oats, rapeseed and biofuel sectors. The UK model is fully incorporated within the EU grain, oilseed, livestock and dairy (GOLD) run by FAPRI at the University of Missouri. Consequently, the UK model is not run in isolation but solves simultaneously within the FAPRI integrated partial equilibrium modelling system. It thereby yields UK projections which are consistent with equilibrium at the EU and world level.

As stated, the UK model consists of sub-models for England, Wales, Scotland and Northern Ireland. In general, supply is modelled for each of the four constituent countries of the UK, while demand is modelled at the UK level. This yields projections of livestock numbers, slaughterings, production, market prices, market receipts, direct payments and selected inputs for each of the countries in the UK. Commodity production from each of the four constituent countries of the UK is summed to yield UK production. Commodity domestic use, imports and exports are projected at the UK level.

The commodity sub-models solve at the European level by ensuring EU export supply equals EU export demand in all markets. The key price in each model is adjusted until equilibrium is attained. Changes in the key price lead to adjustments not only in supply and utilisation in the key country, but via price linkage equations to changes in the supply and utilisation totals in all the other markets modelled. The iterative equilibrating process continues until all product markets in all years are in equilibrium (net EU export supply equal to net EU export demand). Thus, the UK commodity prices are consistent with equilibrium at the EU-level. Within the Baseline world prices are based on the projections of world prices from the Global FAPRI model generated for the World Outlook (FAPRI, 2009). When a policy scenario is undertaken, a reduced form world model is used which mimics FAPRI's Global modelling system's reaction to changes in trade from the EU through representative world prices. Trade for the EU is subject to the constraints of either the agreements made under the Uruguay Round Agreement on Agriculture (URAA) or scenario assumptions.

The UK model covers the following commodities: dairy, beef, sheep, pigs, poultry, wheat, barley, oats, rapeseed and liquid biofuels.

The UK dairy model consists of submodels for liquid milk, cheese, butter, skim milk powder and whole milk powder. The producer price of liquid milk in England and Wales, Scotland and Northern Ireland is modelled as a weighted function of the prices of the dairy commodities cheese, butter, SMP and WMP. The UK has experienced difficulties in filling its milk quota in recent years. The model assumes milk production is equal to the quota providing milk production yields economic rents. If milk producer prices, however, fall below certain levels, milk production is determined by upward sloping supply functions in each country. Milk production per cow is modelled as a function of a linear trend to proxy for technical change and producer's milk price. Finally, dairy cow numbers are derived as an identity, whereby milk production is divided by milk production per cow.

There are four livestock models in the FAPRI-UK system. The beef, pig and sheep models share a similar structure. The key supply side variable in each of the livestock models is the stock of female breeding animals (cows, sows, and ewes). This stock determines the number of young animals available for fattening and/or slaughter, which in turn determine meat production. Owing to its much shorter production cycle and the lack of Common Agricultural Policy (CAP) policy measures, the poultry model is much simpler. It does not include animal numbers, but models production directly.

The various livestock models are linked primarily through their demand side specifications. The demand side specifications are log specifications of per capita demand. Per capita meat demand is modelled as a function of the prices of the meat in question and of the other meats, all of which are all assumed to be gross and net substitutes in consumption. All of the meat goods are normal, none are treated as luxuries. The beef production model is linked with the dairy models via cow slaughter and calf production from the dairy herd.

Within the crops model, land is allocated as a two-step process. Firstly, total cereal and oilseed area is projected as a function of weighted returns, where the weight reflects the share of the grain in total grain area. Having determined total cereal and oilseed area, land is distributed across different crops on the basis of expected returns of the crop in question relative to the other crops. Crop yield per hectare is primarily projected as a function of a trend term, which reflects technology change. To a lesser degree, yields are also affected by prices (small positive impact reflecting higher-yielding varieties from induced innovation) and area devoted to crop production (negative impact due to lower productivity as area increases). The supply of oilseed meals and oils is also projected. Production of oil and meal for each of the oilseeds is determined by the quantities crushed times the appropriate extraction rate.

The model incorporates variables representing the major policy instruments associated with the CAP, including decoupled direct payments, milk quotas, intervention prices and modulation. In addition, the modelling system contains variables representing external trade commitments made by the EU, including export subsidies, tariff rate quotas and import tariffs. These policy variables can be changed to run scenarios for the purposes of policy analysis. When undertaking policy analysis the modelling system is firstly simulated to generate Baseline projections based on the assumptions that current policies remain in place, specific macroeconomic projections hold and average weather conditions apply. Baseline projections of key variables for each country in the UK are generated for a ten year period. Baseline projections provide a benchmark against which projections derived from policy scenarios can be compared and interpreted. The modelling system is then further simulated with changes to policy variables and the results are compared against the Baseline to isolate the policy effects. Baseline projections are presented in this paper for illustration purposes only and should not be treated as forecasts. No policy variables are changed for the purposes of this paper.

2.2 GHG Sub-Model

2.2.1 Introduction to GHG Sub-model

Projections from the main FAPRI-UK modelling system are used as input data for the GHG sub-model. This includes projections on animal numbers, milk yield, fat content of milk, crop areas, crop production, fertiliser price and sector return variables. These agricultural projections are converted into projections of **methane** and **nitrous oxide** emissions from agriculture using the methodology developed by the Intergovernmental Panel on Climate Change (IPCC, 2007a).

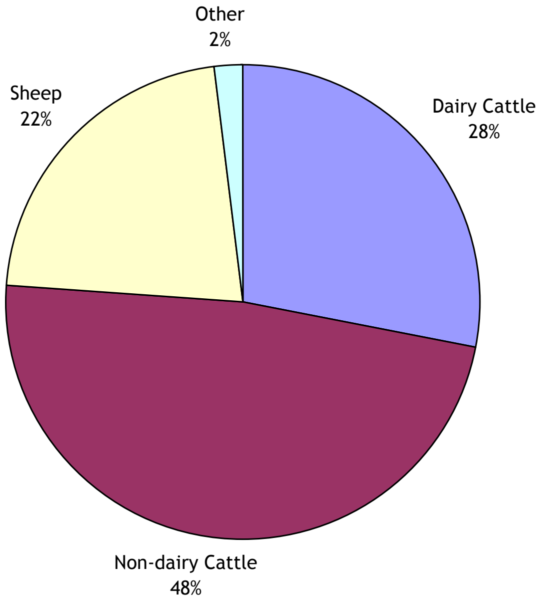
Unlike industrial emissions, which can mostly be monitored at the end-of-pipe, the large number of agricultural producers and the diffuse nature of agricultural GHG emissions means that it is not feasible to directly measure emissions from this sector. Instead, the IPCC methodology approximates the level of GHG emissions from enteric fermentation, manure management practices and soil management using agricultural activity data and average conversion coefficients. Within the UK, historic estimates of GHG emissions are based on UK-specific conversion coefficients and are reported within the GHG inventory (Jackson *et al.*, 2009a). The agricultural estimates are provided by Defra's Land Management Improvement Division through North Wyke Research and are based on the latest scientific research. Historic estimates are reported at the UK-level (Jackson *et al.*, 2009a) and the individual constituent country level (Jackson *et al.*, 2009b). The estimates for England, Wales, Scotland and Northern Ireland are based on agricultural activity data at the individual country level and UK conversion coefficients. Inevitably, there are a number of uncertainties associated with the applied conversion coefficients. Firstly, there are uncertainties associated with the measurement of emissions from different sources. In addition, in computing the coversion coefficients using Tier 2 procedures, conversion coefficients are based on assumptions regarding certain variables (e.g. livestock weight, milk yield and proportion of manure managed in different management systems), which although based on the best information available may be uncertain. Changes in these assumptions would yield different estimates of GHG emissions. Moreover, the applicability of the same conversion coefficients across the UK is questionable due to variations in grazing quality, housing management systems *etc*. However, changes to these conversion coefficients must be based on sound scientific evidence agreed by the scientific community. Part of the remit of a new Defra funded project 'Agricultural GHG Inventory' is to improve the accuracy of the UK inventory.

The methodology used to estimate methane and nitrous oxide emissions within the FAPRI-UK GHG sub-model are outlined below for each emission category, including equations and conversion coefficients from the UK GHG inventory (Jackson *et al.*, 2009a).

2.2.2 Methane emissions from enteric fermentation

Enteric fermentation refers to the production of methane by ruminant animals as a by-product of the digestion process. In 2007 methane emissions from enteric fermentation accounted for 36 per cent of total UK methane and nitrous oxide emissions. As shown in Figure 1, cattle and sheep are the main sources of enteric fermentation in the UK (76 per cent and 22 per cent respectively in 2007). The distinctive feature of ruminants is their digestive system, which due to microbial fermentation in the rumen allows them to digest grass. Methane is produced as a by-product of this microbial fermentation. Non-ruminants such as pigs and poultry have a different digestive system, which does not rely on fermentation, and consequently produce much lower amounts of methane.

Figure 1: Contribution of animal type categories to total UK methane emissions from enteric fermentation in 2007



Note: Other category includes goats, horses, pigs and deer.

Source: UK Greenhouse Gas Inventory National System (2009)

Projected methane emissions from enteric fermentation are calculated using the projections of animal numbers from the main FAPRI-UK modelling system and UK specific conversion coefficients:

Equation 1: Methane emissions from enteric fermentation
= Animal numbers • Enteric Methane Conversion Coefficient (kg CH_4/head/yr)

While the FAPRI-UK modelling system provides projections on the main animal categories – dairy cows, non-dairy cattle, sheep and pigs – it does not cover goats, horses and deer. Within the GHG sub-model it is assumed that these latter animal numbers remain constant over the projection period. As shown in Figure 1, these animals contributed a very small proportion to total UK methane emissions from enteric fermentation in 2007.

The enteric fermentation conversion coefficients are expressed in terms of the amount of methane produced by the animal on an annual basis. These conversion coefficients vary by animal type due to differing size, feed consumption and the manner in which the food is digested. Conversion coefficients for different animal types for 2007 are shown in Table 1. The conversion coefficients for non-dairy cattle, sheep, goats, horses, pigs and deer changed little over the historic period. Between 1990 and 2007 the coefficients for non-dairy cattle increased by 1.3%, sheep by 0.8%, while goats, horses, pigs and deer remained constant. In keeping with the historic period, the projected conversion coefficients for non-dairy cattle, sheep, goats, horses, pigs and deer are held constant over the projection period.

Table 1: Conversion coefficients for methane emissions from enteric fermentation and manure management in 2007

	Enteric Methane ($kg\ CH_4$/head/year)	Methane from manures ($kg\ CH_4$/head/year)
Dairy Cows	105.02	25.79
Non-dairy Cattle	42.95	4.18
Sheep	4.70	0.11
Goats	5.00	0.12
Horses	18.00	1.40
Swine	1.50	7.06
Poultry	0	0.08
Deer	8.82	0.22

Source: UK Greenhouse Gas Inventory National System (2009)

In contrast, the conversion coefficient for dairy cows increased by 19.3% between 1990 and 2007. In order to capture potential year to year variability the conversion coefficient for dairy cows are estimated using the IPCC Tier 2 procedure (IPCC, 1997). Under this procedure, the projected conversion coefficient for dairy cows depends on gross energy requirements, which as shown below is partly determined by fat content of milk and milk yield.

Equation 2: Dairy Cow Emission Factor

= (Gross Energy Intake • Methane Conversion Rate • 365 days/yr) / (55.65 MJ/kg CH4)

where Gross Energy Intake is computed using equations 3 to 8 below

Methane Conversion Rate = 6%

Equation 3: Gross Energy Intake

= $[NE_m + NE_a + NE_l + NE_p)/(NE_{ma}/DE)] / (DE/100)$

where NE_m = net energy required by the animal for maintenance (Equation 4), MJ/day

NE_a = net energy for animal activity (Equation 5), MJ/day

NE_l = net energy for lactation (Equation 6), MJ/day

NE_p = net energy required for pregnancy (Equation 7), MJ/day

NE_{ma}/DE = ratio of net energy available in a diet for maintenance to digestible energy consumed (Equation 8)

DE = digestible energy expressed as a percentage of gross energy

Equation 4: Net Energy for Maintenance

= Cf_i • (Live-weight of animal)$^{0.75}$

where Cf_i = Coefficient for dairy cow net energy maintenance (0.335)

Live-weight of dairy cow = 577.21 kg (in 2007)

Equation 5: Net Energy for Activity
= $C_a \bullet$ Net energy for maintenance
where C_a = Coefficient for dairy cows feeding situation
= % of dairy cows which graze on good quality pasture • 0.17
= 0.46 • 0.17
= 0.0782

Equation 6: Net Energy for Lactation
= kg of milk per day • (1.47 + 0.40 • Fat content of milk %)

Equation 7: Net Energy for Pregnancy
= $C_{pregnancy} \bullet$ Net energy required for maintenance

where $C_{pregnancy}$ = Pregnancy coefficient * Net energy required for maintenance

Equation 8: Ratio of Net Energy Available in a Diet for Maintenance to Digestible Energy Consumed
$= 1.123 - (4.092 \bullet 10^{-3} \bullet DE) + [1.126 \bullet 10^{-5} \bullet (DE)^2] - (25.4/DE)$

where DE = Digestible energy expressed as a percentage of gross energy

Projected fat content of milk and milk yield are projected in line with the FAPRI-UK modelling system. Note, the conversion coefficient for dairy cows also depends on the weight of dairy cows but it is assumed that this remains constant within the modelling system[3]. Within the UK GHG inventory, there was a modest increase in the assumed weight of dairy cows between 1990 and 2007 (approximately 5 per cent).

2.2.3 Methane emissions from manure management

Methane is also produced from the decomposition of manure in anaerobic conditions such as slurry tanks. In contrast, manure that is deposited on pastures or which is dried and spread on land produces low levels of methane (Jackson *et al.*, 2009a). Thus, the amount of methane produced depends on the way manure is managed. In 2007 methane emissions from manure management accounted for 7 per cent of total UK methane and nitrous oxide emissions.

The methane producing potential of manure and the assumed proportion of manure managed in each manure management system within the UK GHG inventory is shown in Table 2. Within the UK inventory a relatively high proportion of dairy cattle and pig manure is handled in liquid systems (approximately 30 per cent), which gives rise to anaerobic respiration and the emission of methane. Consequently, these animals account for a large share of UK methane emissions from manure management (Figure 2). A much lower proportion of beef cattle manure is handled in liquid systems (6 per cent), while sheep are predominantly kept on pastures.

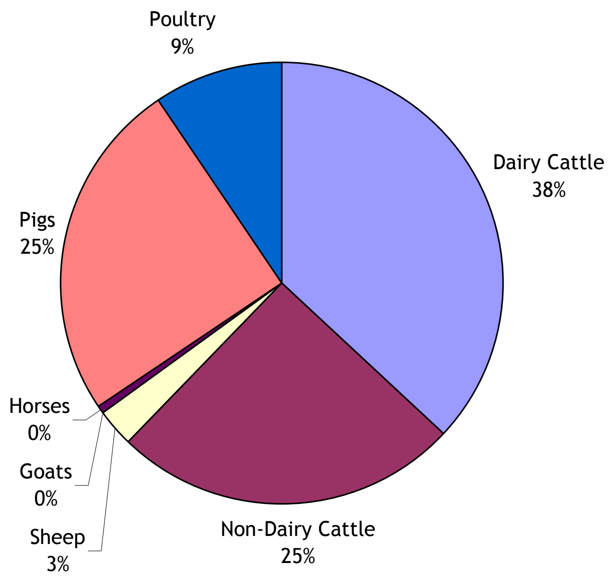
[3] This assumption can be modified if reliable information were forthcoming on the changes in projected weight of dairy cows.

Table 2: Fraction of manure handled using different manure management systems and methane producing potential

	Dairy cattle	Non-dairy cattle	Sheep	Pigs	Poultry	Methane Conversion Factor %
Liquid system	30.6	6	0	31.3	0	39
Daily Spread	14.1	23.0	0	6.3	0	0.1
Solid Storage	9.8	20.7	2	55.3	0	1
Pasture	45.5	50.5	98	7.2	5.2	1
Other	0	0	0	0	94.9	0

Source: UK Greenhouse Gas Inventory National System (2009)

Figure 2: Contribution of animal type categories to total UK methane emissions from manure management in 2007



Source: UK Greenhouse Gas Inventory National System (2009)

Similar to enteric fermentation, projected emissions from manure management are calculated using projected animal numbers and appropriate UK conversion coefficients:

Equation 9: Methane emissions from manure management

= Animal numbers • Methane from manures conversion coefficient (kg CH_4/head/yr)

Projections for dairy cows, non-dairy cattle, sheep, pigs and poultry are obtained from the main FAPRI-UK modelling system, while goats, horses and deer are held constant. These latter animals represent an insignificant proportion of total UK methane emissions from enteric fermentation (Figure 2).

As shown in Table 1, the GHG inventory conversion coefficients vary across animal type according to volatile solid excretion rate, methane producing potential of manure and assumed proportion of manure managed in each manure management system. Within the inventory it is assumed that the proportion of manure managed in each manure management system is the same in England, Wales, Scotland and

Northern Ireland. Unless new information on manure management systems across the UK is forthcoming, the same assumption is incorporated within the FAPRI-UK GHG model. As with enteric fermentation, the conversion coefficients for non-dairy cattle, sheep, pigs, poultry, goats, horses and deer showed negligible variation over the historic period and consequently, projected coefficients within the FAPRI-UK GHG model are held constant over the projection period. For dairy cows, the projected methane from manure conversion coefficient is calculated using the IPCC Tier 2 procedure and thus varies with the gross energy requirement (equations 10 and 11).

Equation 10: Dairy Cow Conversion Coefficient form Manure management

= VSi • 365 days/year • Bo • 0.67 kg/m3 • Σ(j) MCFj • MSj

where VS = Daily VS excreted for dairy cows (kg) – see equation 11 below

Bo = Methane producing capacity of manure (0.24 m^3/kg of VS)

MCFj = CH_4 conversion factors for each manure management system

MSj = Fraction of dairy cow's manure handled using manure system *j*

Equation 11: Volatile Solid Excretion Rates

= GE • (1 kg-dm/18.45 MJ) • (1 – DE/100) • (1 – ASH/100)

where: GE = Estimated daily average feed intake in MJ/day

DE = Digestible energy of the feed (74%)

ASH = Ash content of the manure (8%)

2.2.4 Nitrous oxide emissions from manure management

Nitrous oxide emissions are also produced from the management of animal manure during storage, before it is added to the soil. In 2007 nitrous oxide emissions from manure management accounted for 4 per cent of total UK methane and nitrous oxide emissions. Within the UK GHG inventory, nitrous oxide produced during the storage and treatment of manure is estimated for three sources – (i) slurry manure stored in a tank, (ii) manure collected in solid form and stored in bulk form for a period of time (e.g. scrapings from farm-yard) and (iii) other (includes poultry litter and stable manure). Manure that is deposited directly on soils by livestock (i.e. manure which is unmanaged) is captured under the category 'Pasture, range and paddock' within agricultural soils. As shown in Figure 3, the majority of emissions are from 'solid storage and dry lot'. Emissions from 'liquid systems' are relatively low since the IPCC panel judged that emissions from this source are negligible, as reflected in the default emission factor (IPCC, 2006).

Projected nitrous oxide emissions are estimated by multiplying the projected total amount of nitrogen excretion in each type of manure management system [projected animal numbers multiplied by emission factors for nitrogen excretion for various animal types (Table 3) and the assumed distribution of manure management system for each animal type (Table 2)] by a conversion coefficient for that type of manure management system.

Equation 12: Nitrous Oxide Emissions from Manure Management

$= 44/28 \bullet \sum N_{(T)} \bullet Nex_{(T)} \,.\, AWMS_{(W)} \bullet EF_{(AWMS)}$

where 44/28 = Conversion of N_2O-N emissions to N_2O emissions

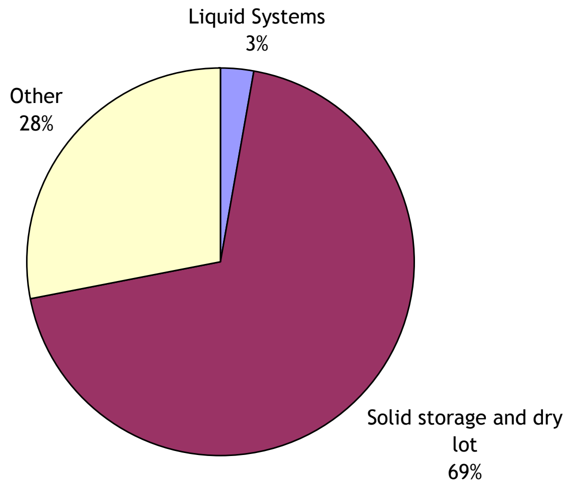
$N_{(T)}$ = Number of animals of type T

$Nex_{(T)}$ = N excretion of animals of type T (kg N/animal/yr)

$AWMS_{(W)}$ = Fraction of Nex that is managed in one of the different waste management systems of type W

$EF_{(AWMS)}$ = N_2O emission factor for animal waste management system (kg N_2O-N/kg of Nex in AWMS)

Figure 3: Contribution of manure management systems to total UK nitrous oxide emissions from manure management in 2007



Source: UK Greenhouse Gas Inventory National System (2009)

Table 3: Nitrogen Excretion Emissions Factors (kg N/head/yr) in 2007

	Nitrogen excretion emission factor
Dairy cows	117.3
Dairy heifers in calf	67
Beef cows and heifers	79
Other cattle > 2	56
Other cattle 1-2 years	56
Other cattle < 1year	38
Sheep	5.3
Pigs	11.2
Poultry	0.5
Goats	20.6
Horses	50
Deer	13

Source: UK Greenhouse Gas Inventory National System (2009) and Jackson *et al.* (2009a)

The FAPRI-UK GHG emission sub-model applies average nitrogen excretion emission factors for sheep, pigs, poultry, goats, horses and deer (shown in Table 3), which are reported in the Common Report Format Inventory Tables (UK Greenhouse Gas Inventory National System, 2009). Applying the average Common Report Format Inventory nitrogen excretion emission factors for dairy cows and non-dairy cows yielded inaccurate historic estimates. Instead, separate nitrogen excretion emission factors are applied for dairy cows, dairy heifers in calf, beef cows and heifers, other cattle > 2, other cattle 1-2 years and other cattle < 1 year (shown in Table 3). The main FAPRI-UK model yields projections of dairy cows, beef cows and total cattle. Projections of dairy heifers in calf, beef cows and heifers, other cattle > 2, other cattle 1-2 years and other cattle < 1 year are obtained by allocating the residual of Total Cattle minus Dairy Cows minus Beef Cows on the basis of historic ratios.

Nitrogen excretion factors for categories other than dairy cows are held constant over the period. The projected dairy cow nitrogen excretion factor is estimated using Tier 2 procedures (see equations 13 and 14 below), which depends on the amount of N consumed annually and the fraction of N consumed that is retained for the production of milk (IPCC, 2006). The amount of N consumed depends on the amount of feed digested by the animal (determined by gross energy requirements) and the protein content of that feed, while the N retained depends on the animal's efficiency of production of animal protein from feed protein.

Equation 13: Annual Dairy Cow N Excretion Rate

$Nex = N_{intake} \bullet (1 - N_{retention})$

where: N_{intake} = the annual N intake per dairy cow, kg N per animal per year (see equation 14)

$N_{retention}$ = fraction of annual N intake that is retained by dairy cow (0.2)

Equation 14: Dairy Cow N Intake

$= (\text{Gross Energy} / 18.45) \bullet (CP/6.25)$

where: Gross Energy = gross energy intake of Dairy Cow (equation 3)

18.45 = conversion factor for dietary gross energy per kg of dry matter

CP = crude protein in diet (derived from equation)

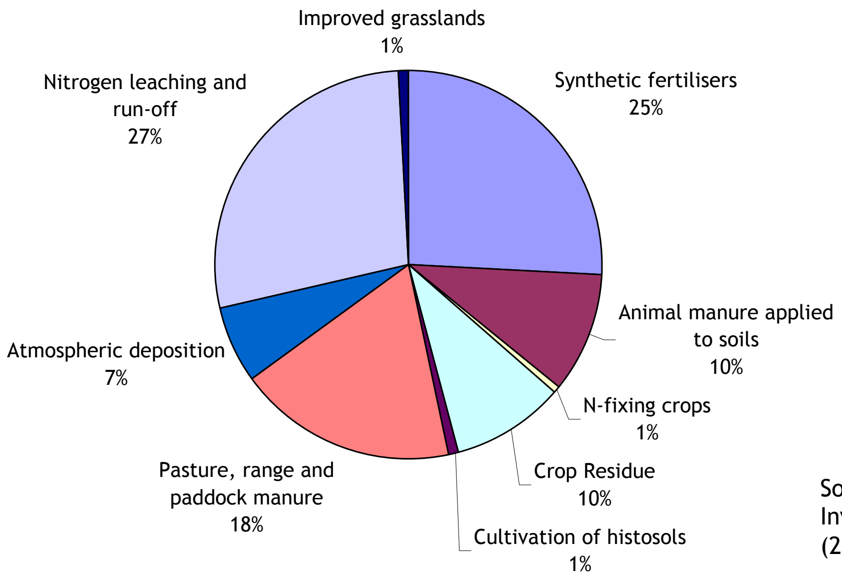
6.25 = conversion from kg of dietary protein to kg of dietary N

Within the FAPRI-UK modelling system the amount of crude protein in the diet is held constant using the last historic year in the inventory. Over the historic period (1990 to 2007) the amount of crude protein in the diet increased by 1.4 per cent. In contrast, the annual dairy cow N excretion rate increased by 20.9 per cent over the same period due to an increase in gross energy requirements.

2.2.5 Nitrous oxide emissions from agricultural soils

The primary source of nitrous oxide emissions is from agricultural soils. In 2007 nitrous oxide emissions from agricultural soils accounted for 54 per cent of total UK methane and nitrous oxide emissions. Direct emissions arise from the application of fertilisers, both synthetic and organic, and manure deposited by grazing animals. Indirect emissions of nitrous oxide also arise from atmospheric deposition, leaching and run-off due to the application of synthetic fertiliser and animal manures. The contribution of direct and indirect sources to total UK nitrous oxide emissions from agricultural soils in 2007 are shown in Figure 4. The methodology used to estimate nitrous oxide emissions from agricultural soils within the FAPRI-UK GHG sub-model for the various sources is discussed in detail below.

Figure 4: Contribution of direct and indirect sources to total UK nitrous oxide emissions from agricultural soils in 2007



Source: UK Greenhouse Gas Inventory National System (2009)

Direct soil emissions

(i) Synthetic fertilisers

Projected emissions of nitrous oxide from the application of synthetic fertiliser depend on projected total use of synthetic fertiliser. The calculation is given by:

Equation 15: Emission of N_2O from synthetic fertiliser application

= 44/28 • Total use of synthetic fertiliser • (1-$Frac_{(GASF)}$) • EF_1

Where 44/28 = Conversion of N_2O-N emissions to N_2O emissions

$Frac_{(GASF)}$ = Fraction of synthetic fertiliser emitted as Nitrate + Ammonia (0.1)

EF_1 = Emission factor for direct soil emissions (0.0125 kg N_2O-N/kg N input)

Projected total use of synthetic fertiliser is the product of synthetic nitrogen application rate and land area, where a distinction is made between tillage land and grassland:

Equation 16: Total use of synthetic fertiliser

= (Nitrgoen per ha tillage land • Tillage area) + (Nitrgoen per ha grassland • Grassland area)

Nitrogen application rates for tillage land and grassland are based on 'The British Survey of Fertilser Practice' data (BSFP, 2008). This survey provides estimates for England & Wales (together) and Scotland. In order to be consistent with the UK GHG inventory, it is assumed that Nitrogen application rates in Northern Ireland are equivalent to those for Scotland. Tillage and grassland nitrogen application rates are modelled as a function of both input and output prices. The fertiliser price is used as measure of input prices, while tillage/grassland returns are used as measure of output prices (equation 17). In addition, a trend term is included within the grassland nitrogen application rate equation to capture the steady decline over recent years.

Equation 17: Nitrogen per ha tillage land / grassland

= fn Crop / Grassland Returns per ha
Fertilser price
Trend (within grassland equations)

Estimated parameters for the tillage and grassland nitrogen application equations are shown in Tables 4 and 5 respectively. Note the equations are estimated in log-log form to allow for non-linear responses. This is particularly important due to the large increase in fertiliser price in 2008. The log-log functional form means that parameter estimates can therefore be interpreted as elasticities. The results indicate that tillage returns influence nitrogen application rates within England & Wales, but not in Scotland. A decrease in output returns creates a disincentive for producers to apply fertilsers. The fertiliser price variable exerts a significant negative impact on tillage application rates in Scotland. Although this variable is not significant at the 10 per cent level in England & Wales, this variable is retained to allow for a small negative impact in these countries (note elasticity is smaller compared to Scotland).

With regards to the Nitrogen per ha grassland equations the returns variable was excluded as preliminary regressions indicated that this variable does not influence grassland application rates. Fertilser price has a similar negative impact on grassland application rates in both England & Wales and Scotland. The estimated elasticities indicate that grassland fertiliser application rates are more responsive to price compared to tillage land. The negative trend term is significant in both England & Wales and Scotland. However, following the 'Baseline projections for agriculture and implications for emissions to air and water' project (ADAS/IGER/SAC, 2007), it is assumed that this negative trend is not sustainable in the long-run as grass production remains important to sustain animal numbers and the impact of the trend term is held constant from 2015 onwards.

Table 4: Nitrogen per ha Tillage Land Equations

		England & Wales	Scotland
Tillage Returns	Coefficient	0.193	0
	Probability	0.046	NA
Fertiliser Price	Coefficient	-0.071	-0.194
	Probability	0.153	0.0199

Table 5: Nitrogen per ha Grassland Equations

		England & Wales	Scotland
Grassland Returns	Coefficient	0	0
	Probability	NA	NA
Fertiliser Price	Coefficient	-0.391	-0.427
	Probability	0.003	0.000
Trend	Coefficient	-0.026	-0.011
	Probability	0.000	0.000

Projected tillage and grassland areas for England, Wales, Scotland and Northern Ireland are derived from agricultural data from the main FAPRI-UK modelling system. The main modelling system provides area projections for wheat, barley, rapeseed and oats. The sum of these four crops represents the majority of total tillage area. The remainder is not captured within the main modelling system (includes for example potatoes and horticultural crops) and is held constant in line with the most recent census for the entire projection period. Summing projected wheat, barley, rapeseed and oat areas plus the constant remainder category yields projected total tillage area.

Projected grassland area is computed as a residual. Projected tillage area and other land categories ('bare fallow', 'sole right rough grazing' 'woodland on holdings' 'other land on holdings' and 'common rough grazing') are deducted from total agricultural area to yield projected grassland area. The other land categories and total agricultural area are held constant during the projection period in line with the most recent census. It would, however, be possible to modify total agricultural area on the basis of more detailed information on loss of agricultural land due to planned growth of urban areas if this information became available for the four constituent countries of the UK.

One area of concern is computed fertiliser use for Northern Ireland. The above procedure in which Scottish tillage and grassland nitrogen fertiliser application rates are multiplied by Northern Ireland tillage/grassland areas is consistent with the approach used within the UK GHG inventory. However, this approach yields a value of total use of synthetic fertiliser that is significantly lower than total fertiliser use published in the Statistical Review of Northern Ireland Agriculture. In order to replicate the GHG inventory figure for nitrous oxide emissions arising from the application of synthetic fertilisers for Northern Ireland, the above procedure is implemented within the modelling system, but it is recognised that this is an area that needs to be further investigated.

(ii) Animal manure applied to soils

Nitrous oxide emissions from animal manure applied to soils arises from the daily spreading of manure and the application of previous stored manures to land. Projected nitrous oxide emissions from the daily spreading of manure are calculated by multiplying the total amount of nitrogen excretion that is daily spread (based on animal numbers, nitrogen excretion emission factors for various animal types and an assumed fraction on nitrogen excretion that is daily spread) by an emission factor for direct soil emissions:

Equation 18: Nitrous oxide emissions from daily spread of animal manure to soils

$$= 44/28 \bullet \sum_T (N_{(T)} \bullet Nex_{(T)} . AWMS_{(DS)}) \bullet EF_1$$

where 44/28 = Conversion of N_2O-N emissions to N_2O emissions

$N_{(T)}$ = Number of animals of type T

$Nex_{(T)}$ = N excretion of animals of type T (kg N/animal/yr)

$AWMS_{(DS)}$ = Fraction of Nex that is daily spread

EF_1 = Emission factor for direct soil emissions (0.0125 kg N_2O-N/kg N input)

Projected nitrous oxide emissions from the application to land of manure previously stored (i.e. slurry, solid storage and dry lot and other) are calculated in a similar manner but with a correction to account for previous nitrous oxide losses during storage:

Equation 19: Nitrous oxide emissions from previously stored manures to soils (liquid, solid storage & dry lot and other)

$= 44/28 \bullet \sum_T (N_{(T)} \bullet Nex_{(T)} . AWMS_{(W)} - N_{(AWMS)}) \bullet EF_1$

where 44/28 = Conversion of N_2O-N emissions to N_2O emissions

$N_{(T)}$ = Number of animals of type T

$Nex_{(T)}$ = N excretion of animals of type T (kg N/animal/yr)

$AWMS_{(W)}$ = Fraction of Nex that is managed in one of the different waste management systems of type W

$N_{(AWMS)}$ = N_2O emissions from animal waste management systems as nitrogen i.e. $N_{(T)} \bullet Nex_{(T)} \bullet AWMS_{(W)} \bullet$ Correction

Correction for liquid = 0.001

solid storage & dry lot= 0.02

other = 0.00484

EF_1 = Emission factor for direct soil emissions (0.0125 kg N_2O-N/kg N input)

(iii) Nitrogen-fixing crops

Nitrogen fixing crops (i.e. legumes) are not captured within the main FAPRI-UK modelling system and thus these emissions are treated as exogenous. Nitrous oxide emissions from nitrogen-fixing crops are held constant at their 2007 value for the entire projection period. As shown in Figure 4, nitrogen-fixing crops contributed less that 1 per cent to total UK nitrous oxide emissions from agricultural soils in 2007.

(iv) Crop residue

Nitrogen is returned to soils through the incorporation of crop residues from both non-nitrogen fixing crops and nitrogen-fixing crops. Within the FAPRI-UK GHG sub-model, emissions of nitrous oxide from the crop residues of wheat, barley, rapeseed and oats are dependent on the projected production of each of these crops. Following the IPCC procedure, the ‘crop residue’ emissions for each of these crops are computed using the following formula:

Equation 20: N_2O emissions from non-N fixing crop residues

= Production of non-N fixing crop • Residue/crop ratio • Dry matter fraction of crop • 0.015 • 44/28 • 0.0125

where 44/28 = Conversion of N_2O-N emissions to N_2O emissions

0.015 = Fraction of nitrogen in non-nitrogen fixing crops

0.0125 = Emission factor for direct soil emissions

The dry mass and residue fractions of wheat, barley, rapeseed and oats are shown in Table 6. The emissions from these four crops account for the vast majority of total UK crop residue emissions. The residual between the crop residue emissions from the four crops included within the FAPRI-UK modelling system and total UK crop residue emissions is held constant at its 2007 value for the entire projection period. Summing the projected emissions from the four main crops and the residual yields projected total nitrous oxide emissions from crop residues.

Table 6: Dry mass and residue fractions of wheat, barley, rapeseed and oats

	Fraction dry mass	Residue/Crop
Wheat	0.855	1.3
Barley	0.855	1.2
Rapeseed	0.91	1.2
Oats	0.855	1.3

(v) Cultivation of histosols (i.e. organic soils)

Nitrous oxide emissions from the cultivation of organic soils are treated as exogenous and held constant at their 2007 value for the entire projection period. Histosols contributed less that 1 per cent to total UK nitrous oxide emissions from agricultural soils in 2007 (Figure 4).

(vi) Pasture, range and paddock manure

Projected nitrous oxide emissions from grazing animals are calculated in the same manner as projected nitrous oxide emissions from manure management (see Equation 12), using a N_2O emission factor for pasture, range and paddock manure (0.02kg N2O-N/kg).

Indirect emissions

(i) Atmospheric deposition

Indirect emissions of nitrous oxide arises from the atmospheric deposition of nitrogen oxides (NO_x) and ammonium (NH_4) due to the application of synthetic fertilisers and animal manure fertilisers. Projected nitrous oxide emissions from atmospheric deposition depend on projected total amount of synthetic fertiliser applied to soils and total amount of excreted animal manure. Following IPCC procedures, the total amount of synthetic fertiliser applied to soils plus the total amount of excreted animal manure is multiplied by appropriate volatilisation factors and an emission factor for atmospheric deposition (see equations 21 and 22 below).

Equation 21: Atmospheric deposition due to synthetic fertilisers

$= 44/28 \bullet N_{(Fert)} \bullet Frac_{(GASF)} \bullet EF_4$

where 44/28 = Conversion of N_2O-N emissions to N_2O emissions

$N_{(Fert)}$ =Total use of nitrogen applied as fertiliser

$Frac_{(GASF)}$ = Fraction of total synthetic fertiliser nitrogen that is emitted as NO_x and NH_4 (0.1 kg N/kg N)

EF_4 = N deposition emission factor (0.01 kg N_2O-N/kg NH_3-N and NO_x-N emitted)

Equation 22: Atmospheric deposition due to waste management systems

$= 44/28 \bullet (N_{(EX)} / (1\text{-}Frac_{(GASM)})) \bullet Frac_{(GASM)} \bullet EF_4$

where 44/28 = Conversion of N_2O-N emissions to N_2O emissions

$N_{(EX)}$ = Total N excreted by animals (i.e. $\sum N_{(T)} \bullet Nex_{(T)} . AWMS_{(W)}$)

$Frac_{(GASM)}$ = Fraction of livestock nitrogen excretion that volatises as NH_3 and NO_x

EF_4 = N deposition emission factor (0.01 kg N_2O-N/kg NH_3-N and NO_x-N emitted)

(ii) Nitrogen leaching and run-off

Indirect emissions of nitrous oxide also arise through leaching and run-off. Within the FAPRI-UK GHG sub-model, projected emissions of nitrous oxide from leaching and run-off are dependent on the projected total amount of synthetic fertiliser applied to soils (equation 23) and projected total amount of excreted animal manure (equation 24).

Equation 23: Leaching and run-off emission of N2O arising from synthetic fertilser application

$= 44/28 \bullet (N_{(FERT)} \bullet (1\text{-}Frac_{(GASF)}) - N_{(SN)}) \bullet Frac_{(LEACH)} \bullet EF_5$

where $N_{(FERT)}$ = Total mass of nitrogen applied as synthetic fertiliser (kg N/yr)

$N_{(SN)}$ = Direct emission of $N_2O_{(SN)}$ as nitrogen (kg N_2O-N/yr)

$Frac_{(GASF)}$ = Fraction of total synthetic fertiliser nitrogen emitted as NO_x + NH_3 (0.1 kg N/ kg N)

$Frac_{(LEACH)}$ = Fraction of nitrogen input to soils lost through leaching and runoff (0.3 kg N/ kg fertiliser or manure N)

EF_5 = Nitrogen leaching/runoff factor (0.025kg N2O-N /kg N leaching/runoff)

Equation 24: Leaching and run-off emission of N2O arising from waste management systems

$= 44/28 \bullet (N_{(EX)} - N_{(AWMS)}) \bullet Frac_{(LEACH)} \bullet EF_5$

where $N_{(EX)}$ = Total N excreted by animals (kg N/yr)

$N_{(AWMS)}$ = Total N content of N2O emissions from waste management systems (kg N_2O-N/yr)

$Frac_{(LEACH)}$ = Fraction of nitrogen input to soils that is lost through leaching and runoff (0.3 kg N/ kg fertiliser or manure N)

EF_5 = Nitrogen leaching/runoff factor (0.025 kg N_2O-N /kg N leaching/runoff)

Other – Improved grassland

Nitrous oxide emissions from improved grassland are treated as exogenous and held constant at their 2007 value for the entire projection period. As shown in Figure 4, improved grassland contributed less that 1 per cent to total UK nitrous oxide emissions from agricultural soils in 2007.

Conversion of GHG Emissions into Carbon Dioxide Equivalents

The global warming potential of methane and nitrous oxide differ. Consequently, in order to quantify the total contribution of UK agriculture to global warming, it is necessary to convert the estimated volumes of these gases into a common measure. Following the agreed IPCC procedure (IPCC, 1996), the global warming potential of different greenhouse gases is defined on the basis of a 100-year time horizon and expressed relative to that of carbon dioxide (CO_2). It is estimated that methane is 21 times more effective at trapping heat in the atmosphere than carbon dioxide, while nitrous oxide is 310 times more effective. Consequently, projected volumes of methane and nitrous oxide are converted into carbon dioxide equivalents by multiplying the estimates by 21 and 310 respectively.

3. Baseline GHG Projections

3.1 Background

Initial GHG emission projections associated with the December 2009 Baseline are outlined below to highlight the nature of the output from the FAPRI-UK modelling system. In line with the FAPRI methodology, the FAPRI-UK Baseline projections are used as a basis for comparison of policy scenarios, *in order to isolate the impact of policy changes by the end of the projection period*. While the Baseline projections are carefully reviewed to assess their robustness, they must not be used on a free standing basis and interpreted as forecasts. The Baseline projections are based on the continuation of existing policies, normal weather conditions and specific macro-economic and other exogenous assumptions over the ten year period. Agricultural production systems are inherently uncertain and following the diminishing role of market management tools under CAP reforms and increased trade liberalisation, EU commodity markets are more susceptible to global shocks.

The Baseline assumes that policies that were in operation in December 2009 remain in place for the duration of the projection period (2009 to 2018). Specifically, the Baseline incorporates features of the Health Check reforms, including further decoupling of direct payments in those EU Member States who have yet to decouple[4]; implementation of compulsory modulation across the EU; the abolition of set-aside; and phased increases of milk quotas, followed by abolition in 2015. In addition to compulsory EU modulation, additional voluntary modulation is applied in each country in the UK at different rates. With regards to international trade, it is assumed that the EU export subsidy limits and import tariffs, agreed under the Uruguay Round Agreements Act (URAA), remain in place. Underlying the Baseline GHG projections it is assumed that current management practices continue; i.e. the projections do not incorporate the impact of mitigations strategies such as changes in feed, breeding, grassland or arable management *etc*. Thus, the Baseline projections provide an indication of the impact of agriculture activity on GHG emissions.

3.2 Baseline Agricultural Activity Projections

(Caution – this section must not be considered as providing forecast information!)

At the global level, during the course of the ten year projection period it is projected that the global economy recovers and consequently sustained income and population growth leads to a growth in global meat consumption. The growth in demand, coupled with strong grain prices, exerts an upward impact on global meat prices. However, based on macro-economic projections from Global Insight, which project that the euro strengthens against the dollar in the long-run, these relatively high prices are not passed on to the EU. Moreover, it is projected that the UK pound strengthens against the euro and thus, UK meat prices are lower relative to EU prices.

[4] Further decoupling entails full decoupling of cereal direct payments, beef special premium and slaughter premium. However, it is assumed that Member States which used the options to retain the Suckler Cow Premium and/or Ewe Annual Premium retain these coupled. In the UK, all decoupled payments were fully decoupled under the 2003 Fischler CAP reforms.

Within the beef sector it is projected that UK beef cow numbers decline over the projection period. In the short-run, it is projected that producers continue to reduce beef cow numbers in response to the decoupling of the Single Farm Payment. In the medium term, projected UK beef cow numbers decline further due to a projected decline in UK beef prices. It is also projected that UK dairy cow numbers decline during the projection period since there is a slight fall in projected milk production combined with a small increase in milk yield. The projected decline in beef and dairy cow numbers leads to a reduction in the calf crop and hence total cattle numbers in the long-run. Overall, it is projected total cattle numbers decline by 9 per cent between 2007 (2007 is used as a reference point since this is the last historic year for GHG estimates) and the end of the projection period (2018).

Within the sheep sector it is projected that ewe numbers fall during the projection period due to the continued impact of the introduction of the Single Farm Payment, the lack of skilled labour and the implementation of electronic identification. The projected decline in ewes leads to a reduction in total sheep numbers. Overall, total sheep numbers are projected to decline by 14 per cent over the projection period. Within the pig sector, it is projected that sow numbers exhibit a small decline over the projection period since a projected decline in price is offset by an easing of costs. Overall, it is projected that total pig numbers decline by 3 per cent between 2007 and 2018. In addition, projected poultry numbers decline by 5 per cent over the projection period.

It is projected that fertiliser use declines over the projection period (minus 10 per cent between 2007 and 2018). Although projected tillage and grassland area increases over the projection period due to the implementation of zero set-aside in 2008, this is more than offset by a projected decline in fertiliser application rates due to high fertiliser prices (driven by strong oil prices) and a negative trend for grassland.

3.3 Baseline GHG Projections

End of the projection period (i.e. 2018) Baseline GHG projections for England, Wales, Scotland, Northern Ireland and the UK are shown in Table 7. More detailed projections for each country are provided in Appendix A. In the following discussion, comparisons are made for the period 2007-2018 (2007 being the latest official historic UK GHG projections).

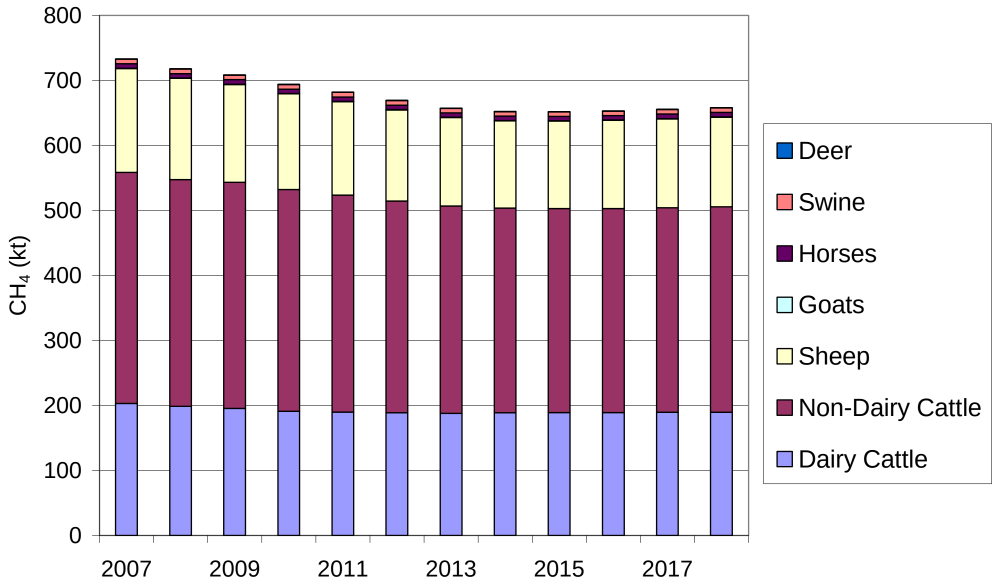
Table 7: GHG Emissions in England, Wales, Scotland and Northern Ireland: Historic and 2018 Projections Associated with December 2009 Baseline

	1990	1995	2007	2018	Percentage Change 1990 to 2018	2007 to 2018
England						
CH_4 Enteric Fermentation (kt)	496.06	479.68	395.83	359.47	-28%	-9%
CH_4 Manure Management (kt)	120.08	116.99	89.93	84.50	-30%	-6%
N_2O Manure Management (kt)	4.69	4.29	3.43	3.18	-32%	-8%
N_2O Agricultural Soils (kt)	65.25	61.33	50.50	47.47	-27%	-6%
Aggregate CH_4 (kt CO_2 eq.)	12,939	12,530	10,201	9,323	-28%	-9%
Aggregate N_2O (kt CO_2 eq.)	21,680	20,342	16,720	15,700	-28%	-6%
Aggregate CH_4 + N_2O emissions (kt CO_2 eq.)	34,619	32,872	26,921	25,023	-28%	-7%
Wales						
CH_4 Enteric Fermentation (kt)	125.15	126.27	108.81	96.03	-23%	-12%
CH_4 Manure Management (kt)	13.94	13.50	11.67	10.66	-24%	-9%
N_2O Manure Management (kt)	0.55	0.51	0.48	0.43	-21%	-10%
N_2O Agricultural Soils (kt)	9.47	9.36	7.00	5.99	-37%	-14%
Aggregate CH_4 (kt CO_2 eq.)	2,921	2,935	2,530	2,240	-23%	-11%
Aggregate N_2O (kt CO_2 eq.)	3,106	3,060	2,321	1,993	-36%	-14%
Aggregate CH_4 + N_2O emissions (kt CO_2 eq.)	6,027	5,995	4,851	4,233	-30%	-13%
Scotland						
CH_4 Enteric Fermentation (kt)	148.01	146.25	130.30	111.86	-24%	-14%
CH_4 Manure Management (kt)	18.11	18.60	17.09	14.36	-21%	-16%
N_2O Manure Management (kt)	0.94	0.89	0.79	0.68	-28%	-14%
N_2O Agricultural Soils (kt)	15.86	15.13	11.43	10.53	-34%	-8%
Aggregate CH_4 (kt CO_2 eq.)	3,489	3,462	3,095	2,651	-24%	-14%
Aggregate N_2O (kt CO_2 eq.)	5,208	4,966	3,788	3,476	-33%	-8%
Aggregate CH_4 + N_2O emissions (kt CO_2 eq.)	8,696	8,428	6,883	6,127	-30%	-11%
Northern Ireland						
CH_4 Enteric Fermentation (kt)	96.15	100.11	98.17	90.95	-5%	-7%
CH_4 Manure Management (kt)	17.71	18.13	17.60	16.96	-4%	-4%
N_2O Manure Management (kt)	0.76	0.78	0.73	0.68	-10%	-6%
N_2O Agricultural Soils (kt)	7.54	7.65	6.26	5.72	-24%	-9%
Aggregate CH_4 (kt CO_2 eq.)	2,391	2,483	2,431	2,266	-5%	-7%
Aggregate N_2O (kt CO_2 eq.)	2,573	2,613	2,165	1,984	-23%	-8%
Aggregate CH_4 + N_2O emissions (kt CO_2 eq.)	4,964	5,096	4,597	4,250	-14%	-8%
UK						
CH_4 Enteric Fermentation (kt)	865.37	852.32	733.11	658.32	-24%	-10%
CH_4 Manure Management (kt)	169.85	167.21	136.29	126.47	-26%	-7%
N_2O Manure Management (kt)	6.94	6.47	5.44	4.97	-28%	-8%
N_2O Agricultural Soils (kt)	98.11	93.47	75.19	69.71	-29%	-7%
Aggregate CH_4 (kt CO_2 eq.)	21,740	21,410	18,257	16,481	-24%	-10%
Aggregate N_2O (kt CO_2 eq.)	32,566	30,981	24,994	23,152	-29%	-7%
Aggregate CH_4 + N_2O emissions (kt CO_2 eq.)	54,305	52,392	43,252	39,633	-27%	-8%

Methane Emissions from Enteric Fermentation

UK methane emissions from enteric fermentation are projected to decline by 10 per cent between 2007 and 2018 (Figure 5 and Table 7). The projected fall in methane emissions reflects the projected decline in cattle and sheep numbers in response to the continued impact of decoupling and the underlying profitability of the beef and sheep sectors. It is projected that the fall in methane emissions is most marked in Scotland (minus 14 per cent) and Wales (minus 12 per cent). Note, on the basis of industry consultation it is assumed that milk yields increase by only a small amount over the projection period since producers place increasing emphasis on reducing feed costs. As a result, it is projected that there is a limited increase in the dairy cow methane enteric fermentation emission factor. In contrast, milk yields, and as a consequence the dairy cow methane enteric fermentation emission factor, increased significantly over the historic period (1990 to 2007). The historic increase in the dairy cow emission factor partially offset the fall in dairy cow numbers.

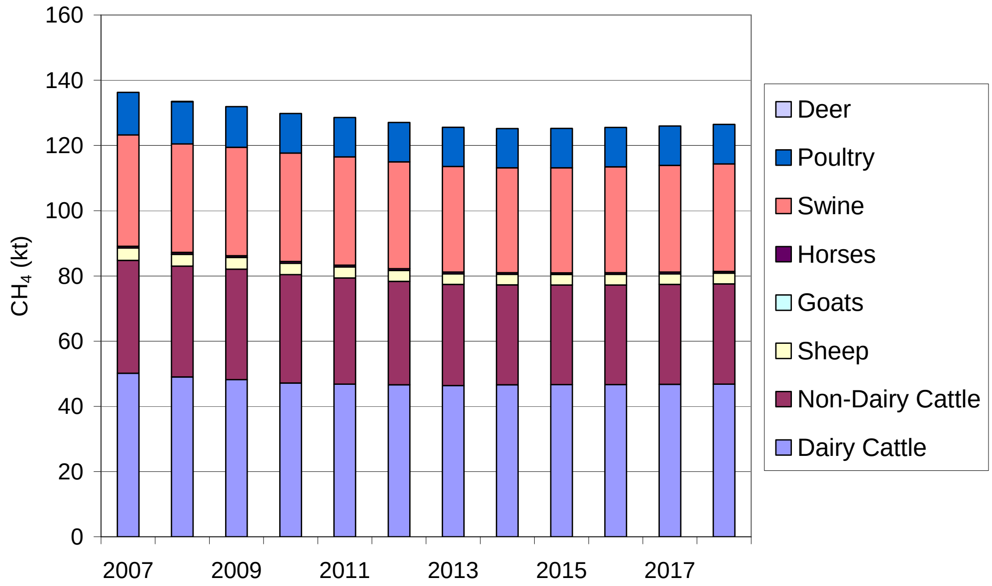
Figure 5: Projected UK Methane Emissions from Enteric Fermentation



Methane Emissions from Manure Management

Projected UK methane emissions from manure management fall by 7 per cent over the projection period. The projected fall in UK methane emissions from manure management is less than that from enteric fermentation due to the contribution of the pig sector. As shown in Figure 6, the pig sector is an important source of methane emissions from manure management (25 per cent in 2007) and it is projected that UK pig numbers fall by a smaller amount than ruminant animals over the projection period. As with enteric fermentation, it is projected that the emission factor for dairy cows only increases by a small amount over the 2007-18 period due to projected milk yield. The projected fall in methane emissions from manure management is greater in Scotland (minus 16 per cent) compared to the rest of the UK since it is projected that total Scottish pig numbers decline significantly over the projection period.

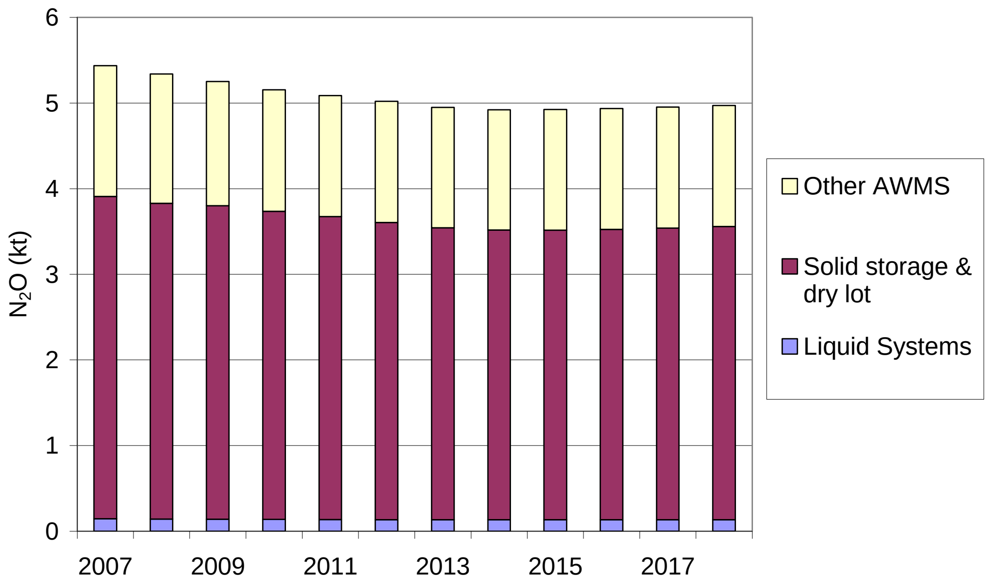
Figure 6: Projected UK Methane Emissions from Manure Management



Nitrous Oxide Emissions from Manure Management

It is projected that UK nitrous oxide emissions from manure management decline by 8 per cent over the projection period (Figure 7). The main component of this source of nitrous oxide is 'solid storage and dry lot' (69 per cent in 2007), which declines due to a projected fall in cattle numbers. The 'other' component (28 per cent in 2007) mostly consists of poultry litter and is projected to fall by 7 per cent over the projection period. The fall in nitrous oxide emissions from manure management is most pronounced in Scotland (minus 14 per cent) due to cattle and pig projections, which adversely effect emissions from 'solid storage and dry lot'.

Figure 7: Projected UK Nitrous Oxide Emissions from Manure Management

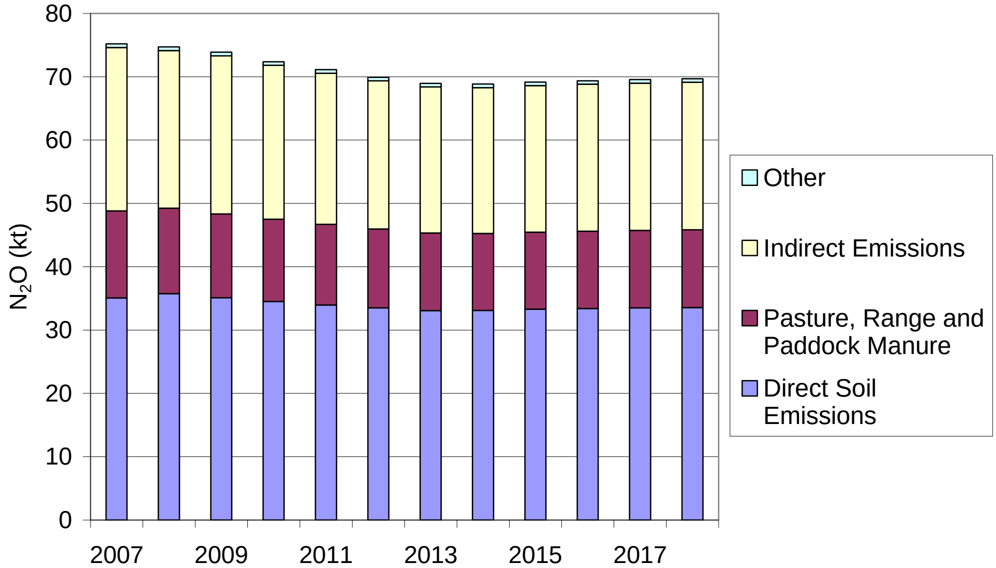


Nitrous Oxide Emissions from Agricultural Soils

Projected UK nitrous oxide emissions from agricultural soils decline by 7 per cent between 2007 and 2018 (Figure 8). The projected decline is greatest in Wales (minus 14 per cent), followed by Northern Ireland (minus 9 per cent), Scotland (minus 8 per cent) and England (minus 6 per cent). Underlying the total nitrous oxide emissions from agricultural soils it is projected that there are marked falls in the categories 'indirect' and 'pasture range and paddock' throughout the UK. However, different responses are evident for the category 'direct emissions'.

While it is projected that there are considerable declines in nitrous oxide emissions in the 'direct emissions' category in Wales (minus 16 per cent) and Northern Ireland (minus 9 per cent), the projected falls are relatively small in Scotland and England (minus 3 per cent in both). These diverse responses reflect differences in direct emissions for the categories 'synthetic fertilisers' and 'crop residues' due to the relative size of the crop sector in different countries in the UK. Tillage crops are of relatively minor importance in Wales and Northern Ireland, but account for a significant proportion of total agricultural area in Scotland and, to an even greater degree, England. It is projected that both tillage and grassland synthetic fertiliser application rates fall over the projection period, but the fall is less pronounced for the former. Consequently, the overall projected application of synthetic fertiliser falls by a smaller amount in England and Scotland, compared to Wales and Northern Ireland. In addition, projected crop residues increase throughout the UK due to the implementation of zero set-aside in 2008 (and abolition of set-aside under the Health Check reforms). This policy change has a smaller upward impact on direct emissions in Wales and Northern Ireland compared to Scotland and England due to the differences in the relative size of the crop sector.

Figure 8: Projected UK Nitrous Oxide Emissions from Agricultural Soils



Total GHG Emissions (CO_2 equivalent)

Overall, it is projected under the December 2009 Baseline that total UK GHG emissions from agriculture, converted into CO_2 equivalent, decline by 8 per cent between 2007 and 2018. The projected decline is greatest in Wales (minus 13 per cent), followed by Scotland (minus 11 per cent), Northern Ireland (minus 8 per cent) and England (minus 7 per cent). The decline is more pronounced in Wales compared to elsewhere in the UK due to projected nitrous oxide emissions from agricultural soils.

4. Conclusions

The overall projected decline in total UK GHG emissions between 2007 and 2018 of 8 per cent under the Baseline is based on the assumption that current management practices continue. This projected decline is driven by a reduction in agricultural activity, i.e. lower livestock numbers and reduced use of fertiliser. Compared to 1990 (the reference year for reduction targets), it is projected that total UK GHG emissions from agriculture fall by 27 per cent. Although significant, this projected decline is less than the UK Climate Change Act reduction target of 34 per cent for 2020. Note, however, these Baseline projections should be treated with care due to the inherent uncertainty of agricultural production systems and the assumptions underlying the analysis. The FAPRI-UK modelling system is designed for the purpose of *isolating policy impacts* by comparing policy scenarios with Baseline projections.

Nonetheless, the Baseline projections suggest that if the agricultural sector is to meet the 34 per cent GHG reduction target mitigation strategies which reduce emissions per unit of output will need to play a significant role. Future analyses using the FAPRI-UK modelling system will assess the impact of mitigation strategies on GHG emissions. Different projected emission factors based on various mitigation strategies, including changes in feed, breeding, grassland management *etc*, will be linked to the main FAPRI modelling system. Linking the models in this manner will provide insights into the combined impact of mitigation strategies and market developments. In addition, the modelling system will be used to assess the impact of all future polices pertaining to the CAP and agricultural trade on GHG emissions.

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Appendix: Projected GHG Emissions for England, Wales, Scotland, Northern Ireland and the UK

Table A1: GHG Emissions in England Associated with December 2009 Baseline

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
CH_4 Enteric Fermentation (kt)												
Dairy Cattle	128.31	125.39	123.69	120.47	119.63	119.07	118.43	119.25	119.43	119.46	119.72	119.92
Non-Dairy Cattle	185.18	181.99	183.44	179.74	175.98	171.71	168.15	165.79	165.10	164.97	165.18	165.73
Sheep	70.54	70.99	68.47	66.18	64.74	63.35	61.70	60.86	61.06	61.49	61.86	62.24
Goats	0.40	0.41	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44
Horses	5.29	5.09	5.13	5.13	5.13	5.13	5.13	5.13	5.13	5.13	5.13	5.13
Swine	5.91	5.78	5.81	5.82	5.82	5.76	5.71	5.67	5.68	5.73	5.78	5.82
Deer	0.19	0.19	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Total	395.83	389.85	387.17	377.98	371.93	365.66	359.75	357.34	357.05	357.41	358.31	359.47
CH_4 Manure Management (kt)												
Dairy Cattle	31.79	31.06	30.64	29.84	29.63	29.50	29.34	29.54	29.59	29.59	29.66	29.71
Non-Dairy Cattle	18.17	17.86	18.00	17.64	17.27	16.85	16.50	16.27	16.20	16.19	16.21	16.26
Sheep	1.67	1.68	1.62	1.57	1.54	1.50	1.46	1.44	1.45	1.46	1.47	1.48
Goats	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Horses	0.41	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Swine	27.84	27.21	27.34	27.40	27.41	27.13	26.85	26.70	26.75	26.96	27.18	27.40
Poultry	10.04	9.99	9.50	9.29	9.25	9.25	9.19	9.18	9.21	9.23	9.24	9.24
Deer	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total	89.93	88.21	87.52	86.16	85.51	84.64	83.76	83.55	83.62	83.84	84.17	84.50
CH_4 Total Agriculture (kt)	485.76	478.06	474.69	464.13	457.45	450.30	443.51	440.90	440.66	441.26	442.48	443.97
N_2O Manure Management (kt)												
Liquid Systems	0.09	0.09	0.09	0.09	0.09	0.09	0.08	0.09	0.09	0.09	0.09	0.09
Solid storage & dry lot	2.22	2.18	2.18	2.15	2.12	2.08	2.05	2.04	2.04	2.04	2.05	2.06
Other AWMS	1.12	1.11	1.06	1.04	1.03	1.03	1.03	1.02	1.03	1.03	1.03	1.03
Total	3.43	3.38	3.33	3.27	3.24	3.20	3.16	3.15	3.15	3.16	3.17	3.18
N_2O Agricultural Soils (kt)												
Direct Soil Emissions	25.95	26.98	26.03	25.99	25.47	25.13	24.78	24.82	24.98	25.05	25.10	25.13
Pasture, Range and Paddock Manure	7.33	7.23	7.15	6.99	6.86	6.74	6.63	6.58	6.58	6.60	6.62	6.64
Indirect Emissions	16.91	16.45	16.33	16.10	15.76	15.47	15.23	15.23	15.31	15.34	15.36	15.38
Other	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
Total	50.50	50.98	49.82	49.40	48.40	47.66	46.96	46.94	47.18	47.31	47.40	47.47
N_2O Total Agriculture (kt)	53.94	54.36	53.15	52.67	51.64	50.86	50.12	50.09	50.33	50.46	50.57	50.64
Conversion to CO_2 equivalent												
Aggregate CH_4 (kt CO_2 eq.)	10,201	10,039	9,969	9,747	9,606	9,456	9,314	9,259	9,254	9,266	9,292	9,323
Aggregate N_2O (kt CO_2 eq.)	16,720	16,852	16,477	16,329	16,008	15,766	15,538	15,528	15,603	15,644	15,675	15,700
Aggregate CH4 + N2O emissions (kt CO_2 eq.)	26,921	26,892	26,446	26,075	25,615	25,222	24,852	24,787	24,857	24,910	24,967	25,023

Table A2: GHG Emissions in Wales Associated with December 2009 Baseline

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
CH_4 Enteric Fermentation (kt)												
Dairy Cattle	24.37	24.16	23.80	23.27	23.13	23.02	22.90	23.02	23.06	23.06	23.10	23.13
Non-Dairy Cattle	39.61	38.94	38.66	37.81	37.15	36.36	35.73	35.17	34.95	34.86	34.83	34.87
Sheep	43.92	41.63	40.26	40.15	39.18	37.88	36.98	36.60	36.62	36.76	36.95	37.15
Goats	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Horses	0.83	0.77	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
Swine	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Deer	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total	108.81	105.58	103.62	102.12	100.35	98.15	96.49	95.68	95.51	95.56	95.77	96.03
CH_4 Manure Management (kt)												
Dairy Cattle	5.97	5.91	5.83	5.70	5.66	5.64	5.61	5.64	5.64	5.65	5.65	5.66
Non-Dairy Cattle	3.84	3.78	3.75	3.67	3.60	3.53	3.46	3.41	3.39	3.38	3.38	3.38
Sheep	1.04	0.99	0.96	0.95	0.93	0.90	0.88	0.87	0.87	0.87	0.88	0.88
Goats	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Horses	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Swine	0.17	0.15	0.16	0.13	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.12
Poultry	0.59	0.56	0.57	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
Deer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	11.67	11.45	11.32	11.06	10.93	10.79	10.67	10.64	10.63	10.62	10.64	10.66
CH_4 Total Agriculture (kt)	120.48	117.02	114.94	113.19	111.28	108.94	107.16	106.32	106.14	106.18	106.40	106.69
N_2O Manure Management (kt)												
Liquid Systems	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Solid storage & dry lot	0.36	0.35	0.35	0.34	0.33	0.33	0.32	0.32	0.32	0.32	0.32	0.32
Other AWMS	0.11	0.10	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Total	0.48	0.47	0.47	0.46	0.45	0.44	0.44	0.43	0.43	0.43	0.43	0.43
N_2O Agricultural Soils (kt)												
Direct Soil Emissions	2.14	1.95	2.02	1.89	1.86	1.82	1.80	1.78	1.79	1.80	1.80	1.80
Pasture, Range and Paddock Manure	2.22	2.14	2.09	2.07	2.03	1.98	1.94	1.93	1.93	1.93	1.93	1.94
Indirect Emissions	2.56	2.36	2.39	2.28	2.25	2.20	2.16	2.15	2.15	2.15	2.16	2.16
Other	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Total	7.00	6.53	6.59	6.33	6.23	6.08	5.99	5.94	5.95	5.96	5.98	5.99
N_2O Total Agriculture (kt)	7.49	7.00	7.05	6.78	6.68	6.52	6.43	6.38	6.39	6.40	6.41	6.43
Conversion to CO_2 equivalent												
Aggregate CH_4 (kt CO_2 eq.)	2,530	2,457	2,414	2,377	2,337	2,288	2,250	2,233	2,229	2,230	2,234	2,240
Aggregate N_2O (kt CO_2 eq.)	2,321	2,171	2,187	2,103	2,070	2,022	1,992	1,977	1,980	1,984	1,988	1,993
Aggregate CH4 + N2O emissions (kt CO_2 eq.)	4,851	4,629	4,601	4,480	4,407	4,310	4,242	4,209	4,209	4,213	4,222	4,233

Table A3: GHG Emissions in Scotland Associated with December 2009 Baseline

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
CH_4 Enteric Fermentation (kt)												
Dairy Cattle	20.67	19.17	19.15	18.49	18.31	18.16	18.01	18.14	18.13	18.11	18.13	18.14
Non-Dairy Cattle	72.59	70.97	69.37	67.60	65.47	63.44	61.66	60.81	60.80	61.12	61.62	62.21
Sheep	35.69	33.82	32.94	32.18	31.42	30.45	29.38	28.89	29.14	29.56	29.98	30.31
Goats	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Horses	0.59	0.58	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Swine	0.69	0.65	0.59	0.56	0.54	0.51	0.50	0.49	0.49	0.49	0.49	0.49
Deer	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Total	130.30	125.27	122.76	119.53	116.44	113.27	110.26	109.03	109.26	109.98	110.92	111.86
CH_4 Manure Management (kt)												
Dairy Cattle	4.96	4.60	4.60	4.44	4.40	4.36	4.33	4.36	4.36	4.35	4.35	4.36
Non-Dairy Cattle	6.91	6.75	6.60	6.43	6.23	6.04	5.87	5.78	5.78	5.81	5.86	5.92
Sheep	0.85	0.80	0.78	0.76	0.74	0.72	0.70	0.68	0.69	0.70	0.71	0.72
Goats	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Horses	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Swine	3.22	3.08	2.80	2.62	2.53	2.42	2.35	2.30	2.29	2.29	2.30	2.31
Poultry	1.10	1.08	1.04	1.01	1.00	1.00	0.99	0.99	1.00	1.00	1.00	1.00
Deer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	17.09	16.36	15.86	15.31	14.95	14.60	14.28	14.17	14.16	14.21	14.28	14.36
CH_4 Total Agriculture (kt)	147.39	141.63	138.62	134.84	131.39	127.86	124.54	123.20	123.42	124.19	125.20	126.22
N_2O Manure Management (kt)												
Liquid Systems	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Solid storage & dry lot	0.64	0.62	0.60	0.58	0.56	0.55	0.53	0.53	0.53	0.53	0.54	0.54
Other AWMS	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Total	0.79	0.77	0.75	0.72	0.70	0.69	0.67	0.66	0.67	0.67	0.67	0.68
N_2O Agricultural Soils (kt)												
Direct Soil Emissions	4.78	4.70	4.91	4.63	4.62	4.55	4.53	4.54	4.57	4.58	4.60	4.61
Pasture, Range and Paddock Manure	2.55	2.46	2.41	2.34	2.28	2.21	2.15	2.13	2.14	2.16	2.18	2.20
Indirect Emissions	4.00	3.84	3.97	3.73	3.69	3.61	3.56	3.55	3.57	3.59	3.61	3.63
Other	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Total	11.43	11.10	11.38	10.80	10.68	10.47	10.34	10.32	10.37	10.43	10.48	10.53
N_2O Total Agriculture (kt)	12.22	11.87	12.13	11.52	11.39	11.16	11.01	10.98	11.04	11.10	11.16	11.21
Conversion to CO_2 equivalent												
Aggregate CH_4 (kt CO_2 eq.)	3,095	2,974	2,911	2,832	2,759	2,685	2,615	2,587	2,592	2,608	2,629	2,651
Aggregate N_2O (kt CO_2 eq.)	3,788	3,679	3,760	3,572	3,530	3,459	3,414	3,404	3,422	3,440	3,458	3,476
Aggregate CH4 + N2O emissions (kt CO_2 eq.)	6,883	6,654	6,671	6,404	6,289	6,144	6,030	5,991	6,014	6,048	6,088	6,127

Table A4: GHG Emissions in Northern Ireland Associated with December 2009 Baseline

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
CH_4 Enteric Fermentation (kt)												
Dairy Cattle	29.88	29.91	28.82	28.96	28.79	28.66	28.53	28.59	28.61	28.59	28.59	28.59
Non-Dairy Cattle	57.99	56.96	56.12	55.85	55.17	54.38	53.60	53.13	53.01	53.05	53.19	53.39
Sheep	9.46	9.23	8.96	8.67	8.47	8.23	7.92	7.77	7.81	7.90	7.98	8.06
Goats	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Horses	0.19	0.21	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Swine	0.62	0.60	0.63	0.66	0.66	0.66	0.65	0.65	0.65	0.65	0.66	0.66
Deer	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Total	98.17	96.95	94.79	94.38	93.35	92.17	90.96	90.39	90.33	90.44	90.66	90.95
CH_4 Manure Management (kt)												
Dairy Cattle	7.42	7.42	7.15	7.19	7.14	7.11	7.08	7.10	7.10	7.09	7.09	7.10
Non-Dairy Cattle	5.70	5.60	5.52	5.49	5.42	5.35	5.27	5.22	5.21	5.21	5.23	5.25
Sheep	0.22	0.22	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.19	0.19	0.19
Goats	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Horses	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Swine	2.90	2.84	2.98	3.09	3.11	3.08	3.06	3.05	3.06	3.08	3.10	3.12
Poultry	1.35	1.34	1.32	1.30	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29
Deer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	17.60	17.43	17.19	17.28	17.19	17.04	16.90	16.85	16.86	16.88	16.92	16.96
CH_4 Total Agriculture (kt)	115.77	114.38	111.98	111.66	110.54	109.22	107.86	107.24	107.18	107.33	107.58	107.91
N_2O Manure Management (kt)												
Liquid Systems	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Solid storage & dry lot	0.54	0.53	0.53	0.53	0.52	0.51	0.51	0.50	0.50	0.50	0.51	0.51
Other AWMS	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.15	0.16	0.16	0.16	0.16
Total	0.73	0.72	0.71	0.70	0.70	0.69	0.68	0.68	0.68	0.68	0.68	0.68
N_2O Agricultural Soils (kt)												
Direct Soil Emissions	2.19	2.12	2.13	2.01	2.01	1.98	1.97	1.97	1.98	1.99	1.99	1.99
Pasture, Range and Paddock Manure	1.67	1.64	1.61	1.58	1.57	1.54	1.52	1.51	1.51	1.51	1.52	1.52
Indirect Emissions	2.34	2.28	2.28	2.18	2.17	2.14	2.12	2.11	2.12	2.12	2.13	2.14
Other	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Total	6.26	6.11	6.08	5.84	5.82	5.73	5.68	5.65	5.67	5.68	5.70	5.72
N_2O Total Agriculture (kt)	6.98	6.82	6.79	6.54	6.51	6.42	6.36	6.33	6.35	6.36	6.38	6.40
Conversion to CO_2 equivalent												
Aggregate CH_4 (kt CO_2 eq.)	2,431	2,402	2,352	2,345	2,321	2,294	2,265	2,252	2,251	2,254	2,259	2,266
Aggregate N_2O (kt CO_2 eq.)	2,165	2,115	2,105	2,028	2,019	1,990	1,971	1,962	1,967	1,973	1,978	1,984
Aggregate CH4 + N2O emissions (kt CO_2 eq.)	4,597	4,517	4,457	4,373	4,341	4,283	4,236	4,214	4,218	4,226	4,237	4,250

Table A5: GHG Emissions in the UK Associated with December 2009 Baseline

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
CH_4 Enteric Fermentation (kt)												
Dairy Cattle	203.23	198.63	195.46	191.19	189.85	188.90	187.87	189.00	189.23	189.21	189.54	189.78
Non-Dairy Cattle	355.36	348.86	347.59	340.99	333.77	325.89	319.14	314.90	313.85	314.00	314.82	316.19
Sheep	159.62	155.66	150.63	147.18	143.81	139.91	135.99	134.12	134.63	135.71	136.77	137.76
Goats	0.48	0.48	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Horses	6.90	6.66	6.79	6.79	6.79	6.79	6.79	6.79	6.79	6.79	6.79	6.79
Swine	7.25	7.07	7.07	7.06	7.05	6.96	6.88	6.83	6.84	6.89	6.95	7.00
Deer	0.28	0.28	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Total	733.11	717.64	708.34	694.01	682.07	669.25	657.47	652.44	652.14	653.40	655.66	658.32
CH_4 Manure Management (kt)												
Dairy Cattle	50.13	49.00	48.22	47.17	46.84	46.60	46.35	46.63	46.69	46.68	46.76	46.82
Non-Dairy Cattle	34.62	33.98	33.86	33.22	32.52	31.75	31.10	30.68	30.58	30.60	30.67	30.81
Sheep	3.79	3.69	3.57	3.49	3.41	3.32	3.23	3.18	3.19	3.22	3.24	3.27
Goats	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Horses	0.54	0.52	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
Swine	34.13	33.27	33.27	33.23	33.17	32.75	32.37	32.16	32.21	32.44	32.70	32.94
Poultry	13.08	12.96	12.42	12.15	12.10	12.10	12.02	12.01	12.05	12.07	12.09	12.09
Deer	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total	136.29	133.45	131.89	129.81	128.59	127.07	125.61	125.21	125.26	125.56	126.01	126.47
CH_4 Total Agriculture (kt)	869.40	851.09	840.24	823.82	810.66	796.32	783.08	777.65	777.40	778.95	781.67	784.79
N_2O Manure Management (kt)												
Liquid Systems	0.15	0.14	0.14	0.14	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Solid storage & dry lot	3.76	3.69	3.66	3.60	3.54	3.47	3.41	3.39	3.38	3.39	3.41	3.43
Other AWMS	1.53	1.51	1.45	1.42	1.41	1.41	1.41	1.40	1.41	1.41	1.41	1.41
Total	5.44	5.34	5.25	5.16	5.09	5.02	4.95	4.92	4.93	4.94	4.96	4.97
N_2O Agricultural Soils (kt)												
Direct Soil Emissions	35.06	35.75	35.09	34.52	33.97	33.48	33.08	33.11	33.31	33.42	33.49	33.54
Pasture, Range and Paddock Manure	13.77	13.48	13.26	12.98	12.74	12.48	12.24	12.15	12.15	12.19	12.25	12.30
Indirect Emissions	25.80	24.93	24.97	24.30	23.87	23.41	23.08	23.04	23.15	23.21	23.26	23.31
Other	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56
Total	75.19	74.72	73.88	72.37	71.13	69.94	68.97	68.85	69.18	69.38	69.56	69.71
N_2O Total Agriculture (kt)	80.63	80.06	79.13	77.52	76.22	74.96	73.92	73.78	74.10	74.32	74.51	74.68
Conversion to CO_2 equivalent												
Aggregate CH_4 (kt CO_2 eq.)	18,257	17,873	17,645	17,300	17,024	16,723	16,445	16,331	16,325	16,358	16,415	16,481
Aggregate N_2O (kt CO_2 eq.)	24,994	24,818	24,530	24,032	23,628	23,237	22,915	22,870	22,972	23,040	23,099	23,152
Aggregate CH4 + N2O emissions (kt CO_2 eq.)	43,252	42,691	42,175	41,332	40,651	39,960	39,360	39,201	39,298	39,398	39,514	39,633