Natural Environment Valuation Online Tool

Technical Documentation

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Chapter 3a: Agriculture Greenhouse Gases Model

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1. The agricultural greenhouse gas (GHG) module: GHG emissions and sequestration on agricultural land

1.1. Farm greenhouse gases in NEVO

Agriculture is a substantial emitter of GHGs through for example, machinery use, mineral and organic fertiliser use, ruminant livestock, and its impact on both biomass and soil carbon stocks. The NEVO tool provides information to users about the quantity and monetised value of agricultural greenhouse gases across England and Wales for the time period of 2020 - 2060. The tool summarises the average annual amount and value of agricultural greenhouse gas sequestration for each decade taking into account spatially and temporally specific inputs related to climate, soil type, land use, livestock and crop management. The quantity of sequestration is estimated using a tailored version of the Cool Farm Tool (CFT, 2013) and is expressed in tonnes of carbon dioxide equivalent (tCO2e), with negative values corresponding to greenhouse gas emissions. The value of greenhouse gas sequestration is expressed in pounds per year (averaged over the decade) and is calculated using the social cost of carbon (Tol, 2013). Values are discounted using a default discount rate of 3.5% per year.

NEVO users are able to explore farm greenhouse gas sequestration/emissions from the current configuration of land use, or from alternative configurations of land use (e.g. expanding or contracting agricultural areas) using the Alter and Optimise functionality.

Limitations

When users are in Alter or Optimise mode, the calculation of greenhouse gas soil sequestration (amount and value) does not include any additional impact associated with converting from the existing land cover to agriculture or vice versa.

1.2. Introduction

This section discusses the spatially and temporally explicit modelling of greenhouse gas (GHG) flows associated with predicted changes in agricultural land use. There are a range of models available to estimate emissions as a function of land use and site management, from the IPCC Tier 1 methods (IPCC, 2006) to more detailed process-based models such as DNDC (Li et al., 1992), RothC (Coleman and Jenkinson, 1996), or DAYCENT (Parton et al., 1993). These models vary with regard to the data requirements, computational intensity, and time required for interpreting the output. Within this project we chose to use the Cool Farm Tool (CFT, 2013) as a model of intermediate complexity which requires as inputs general activity data and site characteristics provided by the other components of this project. Data inputs and section linkages are described in more detail below.

1.3. Objectives

The aim is to calculate the GHG flows associated with agricultural land use change. GHG flows are calculated as a function of soil type, land-use, and assumed farm management data to enable spatial projections. Further details regarding the caveats relating to emissions excluded from this calculation are given in the methodology section.

1.4. Data

Many soil based emissions from agriculture depend on certain soil characteristics as well as management practices. Bouwman et al. (2002), for example, incorporate such characteristics within an empirical model of soil based nitrous oxide (N2O) and nitric oxide (NO) emissions. To populate this model, the following variables were obtained for the UK from the Harmonized World Soil Database (HWSD) (FAO/IFA/IIASA/ISRIC-WSI/ISSCAS/JRC, 2013): soil texture, soil organic matter (SOM), soil moisture, soil drainage, soil pH bulk density, and direct and indirect N_2O emissions were estimated accordingly. The inputs are presented in more detail in Table 3a.1.

Table 3a.1: Categories for soil parameters as used in CFT.

Soil parameter	Classes
Soil texture	(i) coarse (sand, loamy sand, sandy loam, loam, silt loam, silt) (ii) medium (sandy clay loam, clay loam, silty clay loam) (iii) fine (sandy clay, silty clay, clay)
SOM	SOM<= 1.72 1.72 <= SOM <= 5.16 5.16 <= SOM <= 10.32 SOM>=10.32
Soil moisture	moist dry
soil drainage	poorly drained - for fine soils good drained - for medium and coarse soils
soil pH	pH <= 5.5 5.5 <= pH <= 7.3 7.3 <= pH <= 8.5 pH >= 8.5
Bulk density	values from Harmonised World Soil Database (source below)

Soil parameters from the Harmonized World Soil Database (HWSD) were categorized for soil texture, soil organic matter (SOM), soil moisture, soil drainage, soil pH and bulk density to give background information for calculating GHG

Source: (FAO/IFA/IIASA/ISRIC-WSI/ISSCAS/JRC, 2013).

Predicted land use information was obtained from the agricultural model describing the seven land use categories for farmland as follows: oilseed rape; cereals; root crops; grassland with rough grazing; permanent grazing; temperate grazing and other.

1.5. Methodology

Agriculture is a substantial emitter of GHGs through for example, machinery use, mineral and organic fertiliser use, ruminant livestock, effects of both biomass and soil carbon stocks. Major carbon pools on land persist in living biomass (forests, perennials and tree-cropping systems), in addition to soil carbon.

Since most agricultural produce is for consumption within a period of months to a few years it is common practice (e.g. GHG protocol - GHG, 2013) not to account for photosynthetically fixed carbon in plant biomass or agricultural produce. The soil organic carbon (SOC) pool can be a substantial source or sink for emissions, although, except in the case of organic soils the SOC pool tends to equilibrate under fairly constant land use Jenkinson (1990). As a consequence, the major sources of emissions not related to energy use are nitrous oxide (N_2O) and methane (CH_4). N_2O emissions arise due to the mineralisation of nitrogen in organic matter (in the soil or for example in animal manures), and through the use of synthetic nitrogen fertilisers. Major sources of methane are from ruminant livestock (a function of dry matter intake) and manure management. Since dry matter intake is roughly proportional to animal size the key variables affecting GHG emissions are nitrogen fertiliser for field crops (e.g. Hillier et al., 2011), and number of head for a given livestock species. These were thus the critical input variables required for the GHG modelling component.

Agricultural land is classified into seven categories in NEVO. For each category a representative management regime is identified with specific fertiliser rates and machinery use characteristic of the UK. GHG emissions associated with livestock were incorporated into the analysis implementing the emission factors reported by (IPCC, 2006).

1.5.1. Cool Farm Tool (CFT)

The Cool Farm Tool was employed to calculate GHG flows from agricultural land. This tool was originally developed for farmers to estimate the carbon footprint of crop and livestock products. It was designed to be both simple enough for general agricultural use, but scientifically robust for calculating carbon emissions. The CFT has been tested and adopted by a range of multinational companies who are using it to work with their suppliers to measure, manage and reduce GHG emissions in an effort to mitigate global climate change. The calculation of emissions is done at farm-level based on land use and related information and takes all relevant data on production processes, fertiliser use, energy and transport into account. The tool identifies hotspots and makes it easy for farmers to test alternative management scenarios, revealing those that will have a positive impact on net GHG emissions.

Methodologically the CFT sits between calculators using simple emission factor approaches IPCC (2006, Tier 1) and Process-Based models that require a greater level of data input and training to interpret IPCC (2006, Tier 3). The tool is divided into seven input sections as follows:

- General Information (location, year, product, production area, climate);
- Crop Management (agricultural operations, crop protection, fertilizer use, residue management);
- Sequestration (land use and management, above ground biomass);
- Livestock (feed choices, enteric fermentation, N excretion, manure management);

- Field Energy Use (irrigation, farm machinery, etc.,);
- Primary Processing (factory, storage, etc.,);
- Transport (road, rail, air, ship).

CFT (2013) has been engineered in Microsoft Excel and is currently being adapted for online use.

The CFT employs a multivariate empirical model of Bouwman et al. (2002) to estimate NO and N_2O emissions from fertiliser applications. The model is given as follows.

Equation 3a.1:

$$\mathrm{N_2O} = e^{\mathrm{const}} + \sum_{1}^{n=i} \text{Factor class } (i)$$

Where factor the classes are; fertiliser type x fertiliser application rate, crop type, soil texture, soil organic carbon, soil drainage, soil pH, soil cation exchange capacity, climate type, and application method. Factors were determined by statistical analysis and are given in Bouwman et al. (2002). The model for ammonia (NH_3) emissions differs marginally.

Equation 3a.2:

$$\mathrm{NH_3} = \mathrm{FA} \cdot e \sum_{1}^{n=i} \text{Factor class } (i)$$

,where FA is the amount of fertiliser applied. The model is described in FAO/IFA (2001).

Emissions from the production of nitrogen fertilisers are generally comparable in magnitude to field N_2O emissions. These emissions are often attributed to industry, although since they are produced for agricultural use it is often considered appropriate to incorporate these emissions in agricultural assessments and product carbon foot printing. Embedded emissions in other agro-chemicals are incorporated on a unit active ingredient using figures derived from the Audsley (1997) harmonisation life cycle assessment.

Other embedded emissions (for example in machinery manufacture) are not included. Although this is somewhat inconsistent from a scoping point of view, there is no consensus on how to incorporate these emissions although they are acknowledge to be insignificant relative to other agricultural emissions sources (Whittaker et al., 2013)

For the present analysis we use the first two of the seven inputs for the CFT described earlier; the “General Information”, and “Crop Management,” programmed into MATLAB (2013) to calculate carbon emissions from agriculture for the UK. Therefore, representative management regimes include fertilizer use and emissions for machinery in six of the seven land use categories as shown in Table 3a.2. For the land use category “other” (derived from the June Agricultural Census – JAC, 2013 -, whose method is described in the Agricultural Report) we assume the following approximate breakdown into other land use classes: (i) cereals - 10%, (ii) horticulture - 20%, (iii) other agriculture - 45%, and (iv) woodland - 25%. Woodland is covered separately in Technical Report 3b and so is not considered here. For the horticulture subclass we assumed management as for root crops. For the “other agriculture” subclass we assumed 15% of the 45% to be fallow (no emissions). For the remaining 30% of this subclass we assumed emissions to be an average of those from all other main land use classes.

For land management practices (Table 3a.2) fertiliser use and general management of agricultural land were considered as typically used in the UK (St. Clair et al., 2008; Haverkort and Hillier, 2011; DEFRA 2011a). Fertiliser applications were estimated from DEFRA (2011a) and were weighted for the typical crops used in the UK.

Table 3a.2: Management practices including fertilizer use for different land uses.

Land use	Fertiliser	Fertiliser (organic)	Management
Oilseed rape	N = 191 kg ha^{-1} P_2O_5 = 58 kg ha^{-1} K_2O = 65 kg ha^{-1} CaO = 4400 kg ha^{-1}	N = 172 kg ha^{-1} P_2O_5 = 52 kg ha^{-1} K_2O = 58.5 kg ha^{-1} CaO = 3960 kg ha^{-1}	Ploughing Discing Fertiliser spraying Harvesting
Cereals	N = 146 kg ha^{-1} P_2O_5 = 54 kg ha^{-1} K_2O = 64 kg ha^{-1} CaO = 4000 kg ha^{-1}	N = 131 kg ha^{-1} P_2O_5 = 48.6 kg ha^{-1} K_2O = 57.6 kg ha^{-1} CaO = 3600 kg ha^{-1}	Ploughing Harrowing Gain drilling Roller harrowing Fertiliser spraying Harvesting Baling
Root crops	N = 129 kg ha^{-1} P_2O_5 = 95 kg ha^{-1} K_2O = 165 kg ha^{-1}	N = 116 kg ha^{-1} P_2O_5 = 85.5 kg ha^{-1} K_2O = 148.5 kg ha^{-1}	Ploughing Field Cultivating/ridging Rotary hoeing/bed Tilling Planting Tine harrowing/seed handling & transport Fertiliser spraying Potato harvesting
Grassland with grazing	-	-	-
Permanent grazing	N = 85 kg ha^{-1} P_2O_5 = 21 kg ha^{-1} K_2O = 25 kg ha^{-1} CaO = 4300 kg ha^{-1}	N = 76.5 kg ha^{-1} P_2O_5 = 18.9 kg ha^{-1} K_2O = 22.5 kg ha^{-1} CaO = 3870 kg ha^{-1}	Ploughing Fertiliser Spraying Harvesting
Temporary grazing	N = 118 kg ha^{-1} P_2O_5 = 27 kg ha^{-1} K_2O = 41 kg ha^{-1}	N = 106 kg ha^{-1} P_2O_5 = 24 kg ha^{-1} K_2O = 36.9 kg ha^{-1}	Ploughing Fertiliser Spraying Harvesting

Currently between 5 to 10% of the farms in the UK are considered to be organic Jones and Crane (2009). To reflect this in the study, we reduced all fertiliser use by 5% (Table 3a.2) to accommodate a 5% minimum coverage as organic farms.

Emissions of CH_4 and N_2O from livestock (dairy and beef cows, and sheep) were estimated from (IPCC, 2006). The factors are summarised in Table 3a.3. The calculation refers to a typical average weight of animals in the UK.

Table 3a.3: Emission factors for CH_4 and N_2O from livestock.

Emissions	**Dairy cows (600 kg)**	**Beef cows (300kg)**	**Sheep (65 kg)**
CH_4 from fermentation *($kg\ CH_4\ head^{-1}\ yr^{-1}$)*	117	57	8
CH_4 from manure due to annual temperature (T=13°C) *($kg\ CH_4\ head^{-1}\ yr^{-1}$)*	27	8	0.19
N excretion rate *($kg\ N\ (1000\ kg\ animal\ mass)^{-1}\ day^{-1}$)*	0.48	0.33	0.85
N_2O from manure *(factor)*	0.02	0.02	0.01

Emissions factors per head for livestock

1.6. Validation and caveats

Using the management assumptions for the seven land uses, we obtain a total value for UK nitrate fertiliser use of around 1,331,286 t N/yr. It is noteworthy that the figure for nitrogen use figure somewhat exceeds the total synthetic N use figure from (FAO/IFA, 2001) which is approximately 1,000,000 t/yr, but both numbers are close. The difference can be partly explained by the fact that – for simplicity - we consider synthetic N to be the source of all N in our calculations. In reality a significant proportion of N comes from animal manures sources, for which soil N_2O should still be accounted but production emissions not. This may also lead to a slight overestimate of emissions in our case, however given the uncertainty in the fate of N in the soil (particularly for organic N sources) and consequently N_2O emissions this is unlikely to substantially impact results. The differences may also result from the assumptions we made regarding the seven land use classes. The fertiliser amounts used per ha follow recommendations from and for farmers (DEFRA, 2009b, 2011a; St. Clair et al., 2008; Haverkort and Hillier, 2011) but these generally focus on ideal production scenarios and thus may overestimate inputs when taking into account less productive sites or regions.

In summary, possible reasons for overestimation of the total amount of fertiliser:

- Estimated fertiliser use does not consider organic farms. Calculations of fertiliser and emissions in the model with organic farms will be less;
- The classification of agricultural land into just seven land use categories required simplified assumptions regarding management, and an overestimation of fertiliser may have resulted;
- Most farms in the UK (70% - DEFRA, 2011a) use a type of manure that reduces the general use of chemical fertilisers. In the current estimation we do not consider such uses.

The main reasons of uncertainties in estimations of direct and indirect N emissions from managed soils are related to the certainty of the emission factors, natural variability, partitioning fractions, lack of coverage of measurements and spatial aggregation (IPCC, 2006). Depending on the handling of these uncertainties the calculated N emissions can differ in various studies

Management of crop residues such as straw and other non-harvested crop biomass was not considered in the current study with the assumption that residue is exported from the site. ("Export from farm"). Although management of such residual biomass can be a substantial source of emissions (e.g. IPCC, 2006) it is in practice very difficult to account for. This is due both to a lack of data regarding common practice for its management and attribution or allocation between agricultural sectors. For example, if straw is used in the livestock sector for animal bedding the allocation livestock and cropping system is based on whether it is regarded as a bi-product or co-product of the cropping. In other cases the residue could have a direct influence on the total emissions, mostly by increasing the GHG emissions. The worst case scenarios are burning the residue, composting it or leaving it on the farm, but these are ignored for now.

We also did not include emissions due to the oxidation of organic (e.g. peat and fen) soils. Organic soils contain high densities of C, accumulated over many centuries, because decomposition is suppressed by the absence of oxygen under flood conditions. In order to use this land for agriculture, these soils need to be drained, which aerates the soil, favouring decomposition and therefore high fluxes of CO_2 and N_2O. The global warming potential (GWP) of N_2O over a 100 year time horizon is 298 (IPCC, 2007b) (i.e. effectively meaning that over a 100 year period 1 molecule of N_2O has the same global warming effect as 298 molecules of CO_2). Taking this into consideration, the GHG emissions from the Norfolk and Lincolnshire fens, for example, are probably underestimated. In such cases the possible consequence of exploitation for agricultural purposes is GHG emissions an order of magnitude higher than for mineral soils. Thus, our approach may substantially underestimate GHG emissions in these specific regions.

1.7. Results

Per hectare estimated emissions for each land use class for an example soil type are shown in Table 3a.4. For grazing land there are substantial differences between rough grazing land and improved pasture – with the former being essentially unmanaged except by grazing animals and the latter often receiving substantial fertiliser treatments in addition to other management activities, such as mowing and seeding. It should be noted that this table does not include the emissions from the livestock themselves, as this is a function of stocking rate rather than area per se. Emissions from the animals themselves are treated later. Here rough grazing is assumed - with no fertiliser or pesticides – which results in low emissions from the site (excluding livestock). Agrochemical use is highest for root crops. The "field energy use" reflects the machines used in the process and assuming that the diesel is used.

1.7.1. GHG emissions in CO_2e ha^{-1} yr^{-1}

The GHG emissions per hectare vary as a function of farming system. Lowest values are for rough grassland – predominantly in the Scottish Highlands – on which agricultural production is limited and of relatively low intensity. Those areas in which the bulk of our cereal and field crops are grown have GHG emissions of the order or 1000-2500 kg CO_2e ha^{-1} yr^{-1} in which cases GHG emissions are mostly a function of nitrogen fertiliser use. However, it is worth stating that nitrogen use is generally controlled in the UK, and in good practice nitrogen is efficiently used so that inputs are matched to plant uptake.

Per hectare emissions from the “other” land use class results from (i) 208 kg CO_2e ha^{-1} yr^{-1} (10% cereal emissions), (ii) 279 kg CO_2e ha^{-1} yr^{-1} (20% horticulture/root crops), (iii) 460 kg CO_2e ha^{-1} yr^{-1} (30% of averaged emissions of the other 6 land uses and 15% bare soil with no emissions) and (iv) 0 kg CO_2e ha^{-1} yr^{-1} (25% wood – not considered). So, as a result, the total estimated GHG emissions for “other” land use are 947 kg CO_2e ha^{-1} yr^{-1}.

By considering 5% of all farms to be organic, the results show a clear reduction in the GHG emissions (Table 3a.4) compared to the high fertiliser input for non-organic, intensive grazing grassland. Emissions from livestock are considered separately from the other land management emissions. Average emissions for dairy cows, beef and sheep were obtained by multiplying the (per head) emission factors below by the number of animals in each class within each grid cell. Based on the emission factors (Table 3a.3) from (IPCC, 2006) we calculated the following general GHG emissions for an annual mean temperature of 13°C:

- Dairy cow (600 kg) = 4585 kg CO_2e/head/ yr;
- Beef cow (300 kg) = 1963 kg CO_2 e/head/ yr;
- Sheep (65 kg) = 299 kg CO_2 e/head/ yr.

Table 3a.4: GHG emissions in CO_2e ha^{-1} yr^{-1} for different land use and management regime for one soil type.

		All data in kg CO_2e ha^{-1} yr^{-1}				
Land use	**Fertiliser production**	**Background direct and indirect N_2O**	**Fertiliser induced field emissions**	**Agro-chemicals**	**Field energy use**	**Totals**
Oilseed rape	1451 (1306)	164.2 (164.2)	669 (581)	102.5 (102.5)	113.2	**2450 (2267)**
Cereals	1248 (1123)	164.2 (164.2)	471 (413)	41 (41)	152.1	**2076 (1893)**
Root crops	531 (478)	164.2 (164.2)	404 (356)	164 (164)	130.4	**1394 (1293)**
Grassland with grazing		49.3				**49.3**
Permanent grazing	1090 (981)	48.1 (48.1)	167 (150)	123 (123)	44.4	**1473 (1347)**
Temporary grazing	1253 (1127)	48.1 (48.1)	238 (212)	123 (123)	44.4	1707 (1555)

Model simulations were performed to examine the plausibility of estimates obtained from the analysis. Simulations for crops and grass reflected agricultural land use, yielding estimates of high GHG emissions for regions with intensive cropping or for grasslands with high stocking densities. In the north of the UK (Scotland) and in the west (Wales) rough grazing is the dominant land use with low emissions from soil and plants. The highest GHG emissions for crops go up to 2750 kg CO_2e ha^{-1} yr^{-1}. The GHG emissions from livestock show a different picture with highest emissions in intensive grazed regions (Wales, most of Scotland and north western England). Together, these result in total emissions up to 7700 kg CO_2e ha^{-1} yr^{-1} for intensively grazed regions. The lowest emissions are shown in east Scotland, for unmanaged grassland with a very low grazing intensity.

In general, higher emissions of GHGs results from regions in which there is substantial livestock production. The higher values of emissions (around 7700 kg CO_2e ha^{-1} yr^{-1}) result from areas of permanent grassland (which we have assumed to be improved and thus receive significant fertiliser inputs), where there is intensive dairy, beef, or sheep production. This is often in southern and western parts of GB on lands which are not generally suitable for cereal production. The assumptions regarding input use may influence the magnitude of the emissions from these areas. However, the general effect is robust given the outputs of the land use model, since ruminant livestock are known to be significant sources of GHGs from farming.

The current level of total emissions were calculated to be 51 Mt CO_2e per annum for crop land and livestock in England, Wales and Scotland. DEFRA (2011c) calculated 49 Mt CO_2e for the agricultural sector in the UK in 2009. The close agreement of these numbers is felt to be acceptable given slight differences in the scope of these calculations (our number includes around 5% for energy use and machinery but does not include Northern Ireland.

1.8. Discussion and Conclusion

The MATLAB coding used by the CFT calculates GHG emissions for the seven land uses by assuming corresponding typical management systems. These are generalisations to provide estimates of GHG emissions transferable across the entire country.

Livestock are a major contributor to total GHG emissions, and in particular, the total emissions are highly sensitive to stocking rates particularly for cattle and sheep, which are an important source of CH_4 from both enteric fermentation and from manure, and GWP of CH_4 is 25 times that of CO_2 (IPCC, 2007b).

The inclusion of organic farms reduces GHG emissions due to reduced fertiliser use. Less fertiliser use means lower GHG emissions, which is good in terms of reducing total GHG emissions. But with reduced fertiliser there is often a trade-off in the yield, which has consequences for food production, and may create a driver for land use change if any loss in production is to be compensated for by exploiting lands currently not under agricultural use. There is still a lot of research needed to find the ideal environmental optimum N rate by crop and region to compare with the current economic optima.

1.9 References

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