1. Annual inventory estimates for the UK (WP 1.1)

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1.1 Introduction

This section describes the 2005 UK greenhouse gas inventory for the Land Use, Land Use Change and Forestry sector. The Land Use, Land Use Change and Forestry (LULUCF) sector differs from others in the Greenhouse Gas Inventory in that it contains both sources and sinks of carbon dioxide. The sinks, (or *removals* from the atmosphere), are presented as negative quantities. LULUCF is estimated to have been a net sink since 1999, amounting in 2005 to some –2056 Gg CO_2 equivalent.

The estimates for LULUCF emissions and removals are from work carried out by the Centre for Ecology and Hydrology. The structure of this Section and of the main submission for the National Inventory Report and CRF Tables is based on the Categories of the Common Reporting Format tables agreed at the 9th Conference of Parties to the UNFCCC and contained in FCCC/SBSTA/2004/8 (see also IPCC 2003). The Sector 5 Report Tables in the CRF format for each year from 1990 to 2005 have been submitted using the CRF Reporter. The relationship of this reporting format to that used in pre-2004 NIRs from the UK is discussed in the 2004 National Inventory Report.

Net emissions in 1990 are estimated here to be 2882 Gg CO_2 compared to 2915 Gg CO_2 in the 2004 National Inventory Report. For 2004 a net removal of -1935 Gg CO_2 is estimated here compared to a net removal of -1942 Gg CO_2 in the 2004 Inventory. These small differences are due to revision of the data on conversion of Forest Land to Settlement, which affected the land use transition matrix, and other minor data revisions and corrections described under each category.

1.2 Methods

In the IPCC Good Practice Guidance (GPG) for Land Use, Land Use Change and Forestry (IPCC 2003), a uniform structure for reporting emissions and removals of greenhouse gases was described. This format for reporting can be seen as “land based”: all land in the country is identified as having remained in one of 6 classes (Forest Land, Cropland, Grassland, Wetlands, Settlements, Other Land) since a previous survey, or as having changed to a different (identified) class in the period since the last survey. A land use change matrix can be used to capture all these transitions in a compact manner. At its most basic this would be a 6x6 matrix with the diagonal being the areas that remained unchanged and the off-diagonal entries being the areas that had changed. The reporting structure simplifies this 6x6 structure to a 6x2 structure where the 2 columns describe greenhouse gas fluxes associated with i) land that remained in a specific class or ii) land converted into that class. For each of these 6x2 reporting groups, changes in stocks of carbon for above-ground biomass, below-ground biomass, dead biomass and soil organic matter should be reported, where possible. Specific activities that do not directly cause stock changes of carbon are reported in separate tables, *e.g*. greenhouse gases other than CO_2, but emissions from these activities are combined into the totals in a summary table for the Sector.

The LULUCF GPG allows modification of the basic set of six land classes to match national databases. Further subdivision of the classes by ecosystem, administrative region or the time when the change occurred is also encouraged.

1.2.1 Category 5A- Forest Land

All UK forests are classified as temperate and about 65% of these have been planted since 1921 on land that had not been forested for many decades. The Forest Land category is divided into *Category 5.A.1 Forest remaining Forest Land* and *Category 5.A.2 Land converted to Forest Land*. Category 5.A.1 is disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland. Category 5.A.2 is disaggregated into afforestation of Cropland, Grassland and Settlements and further by a) the four geographical areas of England, Scotland, Wales and Northern Ireland and b) two time periods, 1920 – 1990 and 1991 onwards.

Forest Land remaining Forest Land (5.A.1)

There are about 822,000 ha of woodland in the UK that were established prior to 1921 and therefore fall into category 5.A.1. It is apparent from the comparison of historical forest censuses that some of this forest area is still actively managed (see Thomson in Milne *et al*. 2006), but overall this category is assumed to be in carbon balance because of its age, and hence there is zero carbon stock change.

The carbon stock changes (in living biomass, dead organic matter and soils) are entered as 'Not Occurring' (NO) in the Common Reporting Format tables. The possible contribution of this category to carbon emissions and removals will be considered in more detail in future reporting in association with the work carried out under work package 2.3.

Land converted to Forest Land (5.A.2)

The estimates of changes in carbon stock in the biomass and soils of the forests established since 1920 are based on activity data in the form of the area of forest planted annually, as published by the UK Forestry Commission and the Northern Ireland Department of Agriculture. Activity data are obtained annually from the same national forestry sources, which helps ensure time series consistency of estimated removals. The estimates of emissions and removals due to afforestation were updated with national planting statistics for 2005. The Forestry Commission/Forest Service have also provided spatially disaggregated planting statistics for the first time this year but the methodology for including these data in the main inventory is still under development.

Methodology

The carbon uptake by the forests planted since 1920 is calculated by a carbon accounting model, C-FLOW (Dewar & Cannell 1992, Cannell & Dewar 1995 , Milne *et al.* 1998), as the net change in pools of carbon in standing trees, litter, soil in conifer and broadleaf forests and in products. Restocking is assumed in all forests. The method is Tier 3, as defined in the GPG LULUCF (IPCC 2003). Two types of input data and two parameter sets are required for the model (Cannell & Dewar 1995). The input data are: (a) areas of new forest planted in each year in the past, and (b) the stemwood growth rate and harvesting pattern. Parameter values are required to estimate (i) stemwood, foliage, branch and root masses from the stemwood volume and (ii) the decomposition rates of litter, soil carbon and wood products.

As input data we use the combined area of new private and state planting from 1920 to 2005 for England, Scotland, Wales and Northern Ireland sub-divided into conifers and broadleaves. Restocking is dealt with in the model through the second and subsequent rotations, which occur after clearfelling at the time of Maximum Area Increment (MAI). Therefore areas restocked in each year did not need to be considered separately. The key assumption is that the forests are harvested according to standard management tables. However, a comparison of forest census data over time has indicated that there are variations in the felling/replanting date during the 20th century, i.e. non-standard management. These variations in management have been incorporated into the forest model, and the methodology will be kept under review in future reporting.

The C-FLOW model uses Forestry Commission Yield Tables (Edwards & Christie 1981) to describe forest growth after thinning and an expo-linear curve for growth before thinning. It was assumed that all new conifer plantations have the same growth characteristics as Sitka spruce (*Picea sitchensis* (Bong.) Carr.) under an intermediate thinning management regime. Sitka spruce is the most common species in UK forests, being about 50% by area of all conifer forest. Milne *et al.* (1998) have shown that mean Yield Class for Sitka spruce varied across Great Britain from 10-16 m^3 ha^{-1} a^{-1}, but with no obvious geographical pattern, and that this variation had an effect of less than 10% on estimated carbon uptake for the country as a whole. It has therefore been assumed that all conifers in Great Britain follow the growth pattern of Yield Class 12 m^3 ha^{-1} a^{-1}, but in Northern Ireland Yield Class 14 m^3 ha^{-1} a^{-1} is used. Milne *et al.* (1998) also showed that different assumptions for broadleaf species had little effect on carbon uptake. It is assumed that broadleaf forests have the characteristics of beech (*Fagus sylvatica* L.) of Yield Class 6 m^3 ha^{-1} a^{-1}. The most recent inventory of British woodlands (Forestry Commission 2002) shows that beech occupies about 8% of broadleaf forest area (all ages) and no single species occupies greater than 25%. Beech was selected to represent all broadleaves as it has characteristics intermediate between fast growing species e.g. birch, and very slow growing species e.g. oak. However, using oak or birch Yield Class data instead of beech data has been shown to have an effect of less than 10% on the overall removal of carbon to UK forests (Milne *et al.* 1998). The use of beech as the representative species will be kept under review.

Irrespective of species assumptions, the variation in removals from 1990 to the present is determined by the afforestation rate in earlier decades and the effect this has on the age structure in the present forest estate, and hence on the average growth rate. It can be shown that, if forest expansion continues at the present rate, removals of atmospheric carbon will continue to increase until about 2005 and then will begin to decrease, reflecting the reduction in afforestation rate after the 1970s. This afforestation is all on ground that has not been under forest cover for many decades. Table 1-1 shows the afforestation rate since 1921 and a revised estimate of the present age structure of these forests.

Historical forest census data and the historical annual planting rates were compared in the 2006 report. Forest censuses were taken in 1924, 1947, 1965, 1980 and the late 1990s. The comparison showed that discrepancies in annual planting rates and the inferred planting/establishment date (from woodland age in the forest census) are due to restocking of older (pre-1920) woodland areas and variations in the harvesting rotations. However, there is also evidence of shortened conifer rotations in some decades and transfer of woodland between broadleaved categories (e.g. between coppice and high forest). As a result, the afforestation series for conifers in England and Wales were sub-divided into the standard 59 year rotation (1921-2005), a 49 year rotation (1921-1950) and a 39 year rotation (1931-1940, England only). It is difficult to incorporate non-standard management in older conifer and broadleaved forests into the Inventory because it is not known whether these forests are on their first rotation or subsequent rotations (which would affect carbon stock changes, particularly in soils). Further work is planned for this area.

Table 1-1: Afforestation rate and age distribution of conifers and broadleaves in the United Kingdom since 1921. The afforestation rates and ages of GB forests planted later than 1989 are from planting records but the age distribution for GB forests planted before 1990 is from the National Inventory of Woodland and Trees carried out between 1995 and 1999. The age distribution for Northern Ireland forests is estimated from planting records.

Period	**Planting rate (000 ha a^{-1})**		**Age distribution**	
	Conifers	**Broadleaves**	**Conifers**	**Broadleaves**
1921-1930	5.4	2.4	1.4%	7.9%
1931-1940	7.5	2.1	2.5%	8.5%
1941-1950	7.4	2.2	6.1%	11.9%
1951-1960	21.7	3.1	16.3%	11.6%
1961-1970	30.1	2.6	22.6%	8.4%
1971-1980	31.4	1.1	22.3%	5.9%
1981-1990	22.3	2.2	19.0%	4.9%
1991	13.4	6.8	0.9%	0.6%
1992	11.6	6.5	0.8%	0.6%
1993	10.1	8.9	0.7%	0.8%
1994	7.4	11.2	0.5%	1.0%
1995	9.5	10.5	0.7%	1.0%
1996	7.4	8.9	0.5%	0.8%
1997	7.8	9.5	0.5%	0.9%
1998	7.0	9.7	0.5%	0.9%
1999	6.6	10.1	0.5%	0.9%
2000	6.5	10.9	0.5%	1.0%
2001	4.9	13.4	0.3%	1.3%
2002	3.9	10.0	0.3%	0.9%
2003	3.7	9.3	0.3%	0.9%
2004	2.9	8.9	0.2%	0.8%
2005	2.1	9.2	0.2%	0.9%

The input data for increases in stemwood volume are based on standard Yield Tables, as in Dewar & Cannell (1992) and Cannell & Dewar (1995). These Tables do not provide information for years prior to first thinning so a curve was developed to bridge the gap (Hargreaves *et al.* 2003). The pattern fitted to the stemwood volume between planting and first thinning from the Yield Tables follows a smooth curve from planting to first thinning. The formulation begins with an exponential pattern but progresses to a linear trend that merges with the pattern in forest management tables after first thinning.

The mass of carbon in a forest was calculated from the stemwood volume by multiplying by species-specific wood density, stem:branch and stem:root mass ratios and the fraction of carbon in wood (0.5 assumed). The values used for these parameters for conifers and broadleaves are given in Table 1-2, together with the parameters controlling the transfer of carbon into the litter pools and its subsequent decay. The litter transfer rate from foliage and fine roots is assumed to increase over time to a maximum at canopy closure. A fixed fraction of the litter is assumed to decay each year, half of which is added to the soil organic matter pool, which then decays at its own (slower) rate. Both tree species and Yield Class are assumed to control the decay of litter and soil organic matter. Additional litter is generated at times of thinning and felling.

Table 1-2: Main parameters for forest carbon flow model used to estimate carbon uptake by planting of forests of Sitka spruce (*Picea sitchensis* and beech (*Fagus sylvatica*) in the United Kingdom (Dewar & Cannell 1992)

	P. sitchensis	***P. sitchensis***	***F. sylvatica***
	YC12	**YC14**	**YC6**
Rotation (years)	59	57	92
Initial spacing (m)	2	2	1.2
Year of first thinning	25	23	30
Stemwood density (t m^{-3})	0.36	0.35	0.55
Maximum carbon in foliage (t ha^{-1})	5.4	6.3	1.8
Maximum carbon in fine roots (t ha^{-1})	2.7	2.7	2.7
Fraction of wood in branches	0.09	0.09	0.18
Fraction of wood in woody roots	0.19	0.19	0.16
Maximum foliage litterfall (t ha^{-1} a^{-1})	1.1	1.3	2
Maximum fine root litter loss (t ha^{-1} a^{-1})	2.7	2.7	2.7
Dead foliage decay rate (a^{-1})	1	1	3
Dead wood decay rate (a^{-1})	0.06	0.06	0.04
Dead fine root decay rate (a^{-1})	1.5	1.5	1.5
Soil organic carbon decay rate (a^{-1})	0.03	0.03	0.03
Fraction of litter lost to soil organic matter	0.5	0.5	0.5
Lifetime of wood products	57	59	92

The estimates of carbon losses from afforested soils are based on measurements taken at deep peat moorland locations where afforestation occurred 1 to 9 years previously and at a 26 year old conifer forest (Hargreaves *et al.* 2003). These measurements suggest that long term losses from afforested peatlands are not as great as had been previously thought, settling to about 0.3 tC ha^{-1} a^{-1} thirty years after afforestation. In addition, a short burst of regrowth of moorland plant species occurs before forest canopy closure.

Carbon incorporated into the soil under all new forests is considered in the inventory, and losses from pre-existing soil layers are described by the general pattern measured for afforestation of deep peat with conifers. The relative amounts of afforestation on deep peat and other soils in the decades since 1920 are taken into account. For planting on organo-mineral and mineral soils, it is assumed that the pattern of emissions after planting will follow that measured for peat, but the emissions from the pre-existing soil layers will broadly be in proportion to the soil carbon density of the top 30 cm relative to that same depth of deep peat. A simplified approach was taken to deciding on the proportionality factors, and it is assumed that emissions from pre-existing soil layers will be equal to those from the field measurements for all planting in Scotland and Northern Ireland and for conifer planting on peat in England and Wales. Losses from broadleaf planting in England and Wales are assumed to proceed at half the rate of those in the field measurements. These assumptions are based on consideration of mean soil carbon densities for non-forest in the fully revised UK soil carbon database. The temporary re-growth of ground vegetation before forest canopy closure is, however, assumed to occur for all planting at the same rate as for afforested peat moorland. This assumption agrees with qualitative field observations at plantings on agricultural land in England.

It is assumed in the C-FLOW model that harvested material from thinning and felling is made into wood products. The net change in the carbon in this pool of wood products is reported in Category 5G.

Activity data are obtained consistently from the same national forestry sources, which helps ensure time series consistency of estimated removals.

Estimates of carbon stocks in above-ground living biomass, dead material and soils from the new National Inventory of Woodland and Trees should become available from 2009, which will allow the verification of carbon stock estimates from the C-Flow model.

Data reporting in the Common Reporting Format Tables (IPCC 2003)

The data for carbon stock changes in living biomass, dead organic matter and soils from afforestation are entered in Sectoral Background Table 5.A.2 Land converted to Forest Land. The data are disaggregated into changes resulting from the afforestation of Cropland, Grassland and Settlements and reported by (a) the four geographical areas of England, Scotland, Wales and Northern Ireland, and (b) two time periods, up to 1990 and 1991 onwards. The area associated with each set of disaggregated data is included in Sectoral Background Table 5.A.2.

The removals due to carbon stock changes in harvested wood products calculated here are entered into Sectoral Report Table 5, as “G Other, Harvested Wood Products”.

Planned improvements

The method for estimating removals and emissions due to afforestation is being developed to provide data for grid cells of 20 x 20 km. A Matlab version of C-FLOW that runs with grid input data is now complete. Work is now underway to construct the spatially disaggregated data sets, with GB data sets back to 1990 now complete (see work package 2.3 for further details). This approach is being developed to meet the requirements of the Kyoto Protocol for more geographically explicit data for reporting removals due to afforestation and deforestation under Article 3.3. An investigation of the impact of forest management (species planting mix, thinning, harvest age) on forest carbon stocks and fluxes is also underway, enabled by access to more detailed forest datasets. This will contribute to the reporting of removals due to forest management under Article 3.4.

Work is also planned to investigate further the effect of afforestation on soil carbon, specifically the effect of planting broadleaved trees on ex-agricultural mineral soils. The results of this work should be incorporated into the modelling framework of the inventory by 2009.

1.2.2 Cropland (5B)

The category is disaggregated into *5.B.1 Cropland remaining Cropland* and *5.B.2 Land converted to Cropland*. Category 5.B.1 is further disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland.

Three activities are considered for 5.B.1: the effect on non-forest biomass due to crop yield improvements, the effect of fenland drainage on soil carbon stocks (which occurs only in England) and carbon dioxide emissions from soils due to agricultural lime application to Cropland (which is also disaggregated into application of Limestone ($CaCO_3$) and Dolomite ($CaMg(CO_3)_2$)). Category 5.B.2 is disaggregated into conversions from Forest Land, Grassland and Settlements. These conversions are further disaggregated by a) the four geographical areas of England, Scotland, Wales and Northern Ireland, and b) two time periods, 1950 – 1990 and 1991 onwards.

N_2O emissions from disturbance associated with land use conversion to Cropland are not reported as a study has shown these to be small (Skiba *et al.* 2005). This assessment has been re-examined this year and is discussed in chapter 6.

Cropland remaining Cropland (5.B.1)

Methodology - Changes in non-forest biomass resulting from yield improvements

This is the annual increase in the biomass of cropland vegetation in the UK that is due to yield improvements (from improved species strains or management, rather than fertilization or nitrogen deposition). Under category 5.B.1 an annual value is reported for changes in carbon stock, on the assumption that the annual average standing biomass of cereals has increased linearly with increase in yield between 1980 and 2000 (Sylvester-Bradley *et al.* 2002).

Data are reported as a constant average value in each year.

Methodology – Application of Lime

Emissions of carbon dioxide from the application of limestone, chalk and dolomite to cropland were estimated using the method described in the IPCC 1996 Guidelines (IPCC, 1997a, b, c). Data on the use of limestone, chalk and dolomite for agricultural purposes is reported in BGS (2006). Estimates of the individual materials are provided by the British Geological Survey each year as only their total is published because of commercial confidentiality rules for small quantities. It is assumed that all the carbon within the applied material is released in the year of use.

The method for estimating CO_2 emissions due to the application of lime and related compounds is that described in the IPCC 1996 Guidelines. For limestone and chalk, an emission factor of 120 tC/kt applied is used, and for dolomite application, 130 tC/kt. These factors are based on the stoichiometry of the reaction and assume pure limestone/chalk and dolomite. CO_2 emissions, weight for weight, from limestone and chalk are identical since they have the same chemical formula. Dolomite, however, has a slightly higher emission due to the presence of magnesium.

The published data includes 'material for calcination', which only refers to dolomite. However, some of this calcinated dolomite is not suitable for steel making and is returned for addition to agricultural dolomite – this fraction is reported in BGS (2006) as 'material for calcination' under agricultural end use. Calcinated dolomite, having already had its CO_2 removed, will therefore not cause the emissions of CO_2 and hence is not included here. Lime (calcinated limestone) is also used for carbonation in the refining of sugar but this is not specifically dealt with in the UK LUCF GHG Inventory.

Lime is applied to both grassland and cropland. The annual percentages of arable and grassland areas receiving lime in Great Britain for 1994-2004 were obtained from the Fertiliser Statistics Report 2006 (Agricultural Industries Confederation 2006), and extrapolated to obtain an estimate for 2005. Percentages for 1990-1993 were assumed to be equal to those for 1994.

Uncertainty in both the activity data and emission factor used for this source are judged to be low. The main source of uncertainty in the estimates is caused by non-publication of some data due to commercial restrictions, although these are not judged to be very significant. Time-series consistency is underpinned by continuity in data source.

Methodology – Lowland drainage

Lowland wetlands in England were drained many years ago for agricultural purposes and continue to emit carbon from the soil, i.e. there is an ongoing change in soil carbon stock. Bradley (1997) described the methods used to estimate these emissions. The baseline (1990) for the area of drained lowland wetland for the UK was taken as 150,000 ha. This represents all of the East Anglian Fen and Skirtland and limited areas in the rest of England. This total consists of 24,000 ha of land with thick peat (more than 1 m deep) and the rest with thinner peat. Different loss rates were assumed for these two thicknesses (Table 1-3). The large difference between the implied emission factors is due to the observation that those peats described as 'thick' lose volume (thickness) more rapidly that those peats described as 'thin'. The 'thick' peats are deeper than 1m, have 21% carbon by mass and in general have different texture and less humose topsoil than the 'thin' peats, which have depths up to 1m (many areas ~0.45 m deep) and carbon content of 12% by mass.

Table 1-3: Area and carbon loss rates of UK fen wetland in 1990

	Area	**Organic carbon content**	**Bulk density** kg m^{-3}	**Volume loss rate** $m^3\ m^{-2}\ a^{-1}$	**Carbon mass loss** GgC a^{-1}	**Implied emission factor** gC $m^{-2}\ a^{-1}$
'Thick' peat	$24x10^7\ m^2$ (24,000 ha)	21%	480	0.0127	307	1280
'Thin' peat	$126x10^7\ m^2$ (126,000 ha)	12%	480	0.0019	138	109
Total	**$150x10^7\ m^2$ (150 kha)**				**445**	**297**

The emissions trend since 1990 was estimated assuming that no more fenland has been drained since then and that existing drained areas have continued to lose carbon. The annual loss for a specific location decreases in proportion to the amount of carbon remaining. Furthermore, as the peat loses carbon it becomes more mineral in structure. The Century model of plant and soil carbon was used to average the carbon losses from these fenland soils over time (Bradley 1997): further data on how these soil structure changes proceed with time is provided in Burton (1995).

The emissions due to lowland drainage are obtained from a model driven by activity data from a single source, which provides good time series consistency.

Data Reporting

The net emissions due to increases in non-forest biomass are disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland and entered into Sectoral Background Table 5.B.1 (Cropland remaining Cropland) under carbon stock change in living biomass. The area of land associated with each set of data is also included in Sectoral Background Table 5.B.1.

The emissions in this Category from agricultural lime application are entered into Sectoral Background Table 5 (IV) (Carbon emissions from agricultural lime application). The data are disaggregated by application of limestone and dolomite separately on Cropland (and Grassland).

The emissions in this Category due to lowland drainage are entered into Sectoral Background Table 5.B.1 (Cropland remaining Cropland) under net carbon stock change in soils. This applies only to England so there is no further disaggregation. The area of land associated with lowland drainage is also included in Sectoral Background Table 5.B.1. Emission of CO_2 from drained lowland fens were reported in Category 5D5 (CO_2 Emissions and Removals - Other).

Planned Improvements

These activities will be kept under review, with reference to input data and appropriateness of reporting category.

Land Converted to Cropland (5.B.2)

Methodology - Changes in non-forest biomass stocks resulting from land use change to Cropland

This is the annual change in the carbon stock in vegetation biomass due to all land use change to Cropland, excluding forests and woodland. Estimates of emissions and removals for this category are made using the Countryside Survey Land Use Change matrix approach, with biomass densities weighted by expert judgment.

Changes in carbon stocks in biomass due to land use change are based on the same area matrices used for estimating changes in carbon stocks in soils (see following section). The biomass carbon density for each land type (Table 1-4) is assigned by expert judgement based on the work of Milne & Brown (1997). Five basic land uses were assigned initial biomass carbon densities, then the relative occurrence of these land uses in the four countries of the UK were used to calculate mean biomass carbon densities for each of the IPCC types, Cropland, Grassland and Settlements. Biomass carbon stock changes due to conversions to and from Forest Land are dealt with elsewhere. The mean biomass carbon densities for each land type were then weighted by the relative proportions of change occurring between land types (Table 1-5 to Table 1-8), in the same way as the calculations for changes in soil carbon densities. Changes between these equilibrium biomass carbon densities were assumed to happen in a single year.

Data are reported as a constant average value in each year.

Table 1-4: Equilibrium biomass carbon density (kg m^{-2}) for different land types

Density (kg m^{-2})	Scotland	England	Wales	N. Ireland
Arable	0.15	0.15	0.15	0.15
Gardens	0.35	0.35	0.35	0.35
Natural	0.20	0.20	0.20	0.20
Pasture	0.10	0.10	0.10	0.10
Urban	0	0	0	0
IPPC types weighted by occurrence				
Cropland	0.15	0.15	0.15	0.15
Grassland	0.18	0.12	0.13	0.12
Settlements	0.29	0.28	0.28	0.26

Table 1-5: Weighted average change in equilibrium biomass carbon density (kg m^{-2}) for changes between different land types in England (Transitions to and from Forestland are considered elsewhere)

To \ From	Forestland	Cropland	Grassland	Settlements
Forestland				
Cropland		0	-0.08	-0.13
Grassland		0.08	0	-0.08
Settlements		0.13	0.08	0

Table 1-6: Weighted average change in equilibrium biomass carbon density (kg m^{-2}) for changes between different land types in Scotland. (Transitions to and from Forestland are considered elsewhere)

From / To	Forestland	Cropland	Grassland	Settlements
Forestland				
Cropland		0	-0.02	-0.14
Grassland		0.02	0	-0.09
Settlements		0.14	0.09	0

Table 1-7: Weighted average change in equilibrium biomass carbon density (kg m^{-2}) for changes between different land types in Wales. (Transitions to and from Forestland are considered elsewhere)

From / To	Forestland	Cropland	Grassland	Settlements
Forestland				
Cropland		0	-0.07	-0.13
Grassland		0.07	0	-0.08
Settlements		0.13	0.08	0

Table 1-8: Weighted average change in equilibrium biomass carbon density (kg m^{-2}) for changes between different land types in Northern Ireland. (Transitions to and from Forestland are considered elsewhere)

From / To	Forestland	Cropland	Grassland	Settlements
Forestland				
Cropland		0	-0.08	-0.11
Grassland		0.08	0	-0.06
Settlements		0.11	0.06	0

Methodology – Changes in soil carbon stocks due to land use change to Cropland

Land use change results in soil carbon stock change, because soil carbon density generally differs under different land uses and the land use change initiates a transition from one density value to another. Under the methodology for this activity, all forms of land use change, including deforestation, are considered together and both mineral and organic soils are included.

The method for assessing changes in soil carbon stock due to land use change links a matrix of change from land surveys to a dynamic model of carbon stock change. For Great Britain (England, Scotland and Wales), matrices from the Monitoring Landscape Change (MLC) data from 1947 & 1980 (MLC 1986) and the ITE/CEH Countryside Surveys (CS) of 1984, 1990 and 1998 (Haines-Young *et al.* 2000) are used. Land use in the UK was placed into the GPG categories – Forestland, Grassland, Cropland, Settlements, and Other Land by combining the more detailed categories for the two surveys (Table 1-9 and Table 1-10). The data currently available for the UK does not distinguish wetlands from other types, so land in the UK has been placed into the five other types. Area change data exist for the period up to 1998 and those from 1990 to 1998 are used to extrapolate to the years 1999 to 2005 (Table 1-11).

Table 1-9: Grouping of MLC land cover types for soil carbon change modelling

CROPLAND	GRASSLAND	FORESTLAND	SETTLEMENTS (URBAN)	OTHER LAND
Crops	Upland heath	Broadleaved wood	Built up	Bare rock
Market garden	Upland smooth grass	Conifer wood	Urban open	Sand/shingle
	Upland coarse grass	Mixed wood	Transport	Inland water
	Blanket bog	Orchards	Mineral workings	Coastal water
	Bracken		Derelict	
	Lowland rough grass			
	Lowland heather			
	Gorse			
	Neglected grassland			
	Marsh			
	Improved grassland			
	Rough pasture			
	Peat bog			
	Fresh Marsh			
	Salt Marsh			

Table 1-10: Grouping of Countryside Survey Broad Habitat types for soil carbon change modelling.

CROPLAND	GRASSLAND	FORESTLAND	SETTLEMENTS (URBAN)	OTHER LAND
Arable	Improved grassland	Broadleaved/mixed	Built up areas	Inland rock
Horticulture	Neutral grassland	Coniferous	Gardens	Supra littoral rock
	Calcareous grassland			Littoral rock
	Acid grassland			Standing waters
	Bracken			Rivers
	Dwarf shrub heath			Sea
	Fen, marsh, swamp			
	Bogs			
	Montane			
	Supra littoral sediment			
	Littoral sediment			

Table 1-11: Sources of land use change data in Great Britain for different periods in estimation of changes in soil carbon

Year or Period	Method	Change matrix data
1950 - 1979	Measured LUC matrix	MLC 1947 →MLC1980
1980 - 1984	Interpolated	CS1984 → CS1990
1984 - 1989	Measured LUC matrix	CS1984 → CS1990
1990 - 1998	Measured LUC matrix	CS1990 → CS1998
1999 - 2004	*Extrapolated*	CS1990 → CS1998

In Northern Ireland, less data are available to build matrices of land use change, but for 1990 to 1998 a matrix for the whole of Northern Ireland was available from the Northern Ireland Countryside Survey (Cooper & McCann 2002). The only data available pre-1990 for Northern Ireland are land use areas from the Agricultural Census and the Forest Service (Cruickshank & Tomlinson 2000). Matrices of land use change were then estimated for 1970-80 and 1980-90 using area data. The basis of the method devised assumed that the relationship between the matrix of land use transitions for 1990-1998 and the area data for 1990 is the same as the relationship between the matrix and area data for each of two earlier periods – 1970-79 and 1980-89. The matrices developed by this approach were used to extrapolate areas of land use transition back to 1950 to match the start year in the rest of the UK (Table 1-12).

Table 1-12: Sources of land use change data in Northern Ireland for different periods in estimation of changes in soil carbon. NICS = Northern Ireland Countryside Survey

Year or Period	Method	Change matrix data
1950 - 1969	Extrapolation and ratio method	NICS1990->NICS1998
1970 - 1989	Land use areas and ratio method	NICS1990->NICS1998
1990 - 1998	Measured LUC matrix	NICS1990->NICS1998
1999-2003	*Extrapolated*	NICS1990->NICS1998

For both Great Britain and Northern Ireland the land use change data over the different periods were used to estimate annual changes by assuming that change was uniform across the measurement period. Examples of these annual changes (for the period 1990 to 1999) are given in Table 1-13 to Table 1-16. The data for land use change to and from Forest Land shown in the Tables are adjusted before use for estimating carbon changes to harmonise the values with those used for afforestation and deforestation (described elsewhere).

Table 1-13: Annual changes (000 ha) in land use in England in matrix form for 1990 to 1999. Based on land use change between 1990 and 1998 from Countryside Surveys (Haines-Young *et al.* 2000). Data have been rounded to 100 ha.

To \ From	Forestland	Grassland	Cropland	Settlements
Forestland		8.9	3.4	2.1
Grassland	8.7		55.3	3.4
Cropland	0.5	62.9		0.6
Settlements	1.2	8.5	2.1	

Table 1-14: Annual changes (000 ha) in land use in Scotland in matrix form for 1990 to 1999. Based on land use change between 1990 and 1998 from Countryside Surveys (Haines-Young *et al.* 2000). Data have been rounded to 100 ha.

To \ From	Forestland	Grassland	Cropland	Settlements
Forestland		11.1	0.6	0.2
Grassland	5.0		16.8	0.7
Cropland	0.1	21.4		0.3
Settlements	0.3	2.2	0.1	

Table 1-15: Annual changes (000 ha) in land use in Wales in matrix form for 1990 to 1999. Based on land use change between 1990 and 1998 from Countryside Surveys (Haines-Young *et al.* 2000). Data have been rounded to 100 ha.

To \ From	Forestland	Grassland	Cropland	Settlements
Forestland		2.4	0.2	0.2
Grassland	1.5		5.5	0.6
Cropland	0.0	8.0		0.0
Settlements	0.1	1.8	0.2	

Table 1-16: Annual changes (000 ha) in land use in Northern Ireland in matrix form for 1990 to 1999. Based on land use change between 1990 and 1998 from Northern Ireland Countryside Surveys (Cooper & McCann 2002). Data have been rounded to 100 ha.

To \ From	Forestland	Grassland	Cropland	Settlements
Forestland		1.6	0.0	0.0
Grassland	0.3		5.9	0.0
Cropland	0.0	3.7		0.0
Settlements	0.1	1.0	0.0	

A database of soil carbon density for the UK, based on information on soil type, land cover and carbon content of soil cores, has been available since 1995 (Milne & Brown 1997, Cruickshank *et al.* 1998). These densities included carbon to a depth of 1 m or to bedrock, whichever was the shallower, for mineral and peaty/mineral soils. Deep peat in the North of Scotland was identified separately and depths to 5 m are included. For the 2003 Inventory a complete re-evaluation of the database was carried out (Bradley *et al.* 2005). The three soil survey groups covering the UK and the field data, soil classifications and laboratory methods of each group were harmonized to reduce uncertainty in the final database. The depth of soil considered was also restricted to 1 m maximum as part of this process. The total stock of soil carbon (1990) and the soil carbon densities under different land types in the four devolved areas of the UK are shown in Table 1-17 and Table 1-18.

Table 1-17: Soil carbon stock (TgC = MtC) for depths to 1m under the IPCC land categories

Type \ Region	England	Scotland	Wales	N. Ireland	**UK**
Forestland	108	295	45	20	467
Grassland	995	2,349	283	242	3,870
Cropland	583	114	8	33	738
Settlements	54	10	3	1	69
Other	0	0	0	0	-
TOTAL	**1,740**	**2,768**	**340**	**296**	**5,144**

Table 1-18: Soil carbon densities (kg m^{-2}) in the United Kingdom under the IPCC land categories

	Soil depth 0-30 cm					Soil depth 30-100 cm				
	Organic	**Organo-mineral**	**Mineral**	**Other**	**All**	**Organic**	**Organo-mineral**	**Mineral**	**Other**	**All**
England										
Forestland	22.9	12.2	10.7	3.5	9.2	90.5	8.0	4.3	2.2	6.8
Cropland	17.0	17.3	7.7	2.9	6.7	64.2	6.3	4.3	1.8	4.3
Grassland	19.9	11.7	9.6	3.4	8.3	52.3	7.2	5.0	2.3	6.5
Settlement	10.5	6.6	4.7	2.0	3.9	32.6	1.1	2.4	1.1	2.0
Scotland										
Forestland	22.3	23.7	25.1	4.7	22.6	50.0	11.8	9.0	3.3	20.2
Cropland	22.6	13.9	12.1	3.6	12.2	55.2	4.2	3.3	1.2	3.7
Grassland	22.3	22.7	18.8	3.6	20.2	51.2	8.7	5.8	2.6	18.4
Settlement	11.3	7.8	7.3	1.5	7.2	28.0	2.5	2.3	0.5	2.3
Wales										
Forestland	23.6	12.1	13.7	4.2	11.7	90.8	7.7	4.0	2.8	8.6
Cropland	20.6	9.3	7.5	3.1	6.6	74.5	6.5	4.7	1.8	4.2
Grassland	21.4	10.8	11.0	3.8	9.7	67.4	7.1	5.4	2.7	7.4
Settlement	10.5	5.3	4.6	2.3	4.1	30.4	3.8	2.2	1.3	2.2
Northern Ireland										
Forestland	13.3	20.1	19.6	0.0	17.2	31.0	7.5	13.9	0.0	19.4
Cropland	13.0	8.6	12.8	0.0	12.6	30.3	4.5	8.7	0.0	9.6
Grassland	13.2	20.8	16.1	0.0	16.1	30.8	7.9	11.5	0.0	14.3
Settlement	6.5	9.8	7.4	0.0	7.4	15.2	2.9	5.1	0.0	5.2

The core equation describing changes in soil carbon with time for any land use transition is:

$$C_t = C_f - (C_f - C_0)e^{-kt}$$

where

C_t is carbon density at time t

C_0 is carbon density of initial land use

C_f is carbon density after change to new land use

k is time constant of change

By differentiating we obtain the equation for flux f_t (emission or removal) per unit area:

$$f_t = k(C_f - C_o)e^{-kt}$$

From this equation we obtain, for any inventory year, the land use change effects from any specific year in the past. If A_T is area in a particular land use transition in year T considered from 1950 onwards then total carbon lost or gained in an inventory year, e.g. 1990, is given by:

$$F_{1990} = \sum_{T=1950}^{t=1990} kA_T(C_f - C_o)(e^{-k(1990-T)})$$

A Monte Carlo approach is used to vary the inputs for this equation: the rate of change (k), the area activity data (A_T) and the values for soil carbon equilibrium under initial and final land use (C_f-C_0) for all countries in the UK. The model was run 1000 times using parameters selected from within the ranges described above. The mean carbon flux for each region resulting from this approach is reported as the estimate for the Inventory. An adjustment is made to these calculations for each country to remove increases in soil carbon due to afforestation, as a better value for this is found from the C-Flow model used for the Land converted to Forest Land category. Variations from year to year in the reported net emissions reflect the trend in land use change as described by the matrices of change.

The change in equilibrium carbon density from the initial to the final land use are calculated for each land use category as averages for Scotland, England, Northern Ireland and Wales. The rate of loss or gain of carbon is dependent on the type of land use transition. These averages are weighted by the area of Land Use Change occurring in four broad soil groups (organic, organo-mineral, mineral, unclassified) in order to account for the actual carbon density where change has occurred.

Hence mean soil carbon density change is calculated as:

$$\overline{C}_{ijc} = \frac{\sum_{s=1}^{6}(C_{sijc}L_{sijc})}{\sum_{s=1}^{6}L_{sijc}}$$

This is the weighted mean, for each country, of change in equilibrium soil carbon when land use changes, where:

i = initial land use (Forestland, Grassland, Cropland, Settlements)

j = new land use (Forestland, Grassland, Cropland, Settlements)

c = country (Scotland, England, N. Ireland & Wales)

s = soil group (organic, organo-mineral, mineral, unclassified)

C_{sijc} is change in equilibrium soil carbon for a specific land use transition, L_{sijc}.

The most recent land use data (1990 to 1998) is used in the weighting. The averages calculated are presented in Table 1-19 to Table 1-22.

Table 1-19: Weighted average change in equilibrium soil carbon density (kg m^{-2}) to 1 m deep for changes between different land types in England

To \ From	Forestland	Grassland	Cropland	Settlements
Forestland	0	25	32	83
Grassland	-21	0	23	79
Cropland	-31	-23	0	52
Settlements	-87	-76	-54	0

Table 1-20: Weighted average change in equilibrium soil carbon density (kg m^{-2}) to 1 m deep for changes between different land types in Scotland

To \ From	Forestland	Grassland	Cropland	Settlements
Forestland	0	47	158	246
Grassland	-52	0	88	189
Cropland	-165	-90	0	96
Settlements	-253	-187	-67	0

Table 1-21: Weighted average change in equilibrium soil carbon density (kg m^{-2}) to 1 m deep for changes between different land types in Wales

To \ From	Forestland	Grassland	Cropland	Settlements
Forestland	0	23	57	114
Grassland	-18	0	36	101
Cropland	-53	-38	0	48
Settlements	-110	-95	-73	0

Table 1-22: Weighted average change in equilibrium soil carbon density (kg m^{-2}) to 1 m deep for changes between different land types in Northern Ireland

To \ From	Forestland	Grassland	Cropland	Settlements
Forestland	0	94	168	244
Grassland	-94	0	74	150
Cropland	-168	-74	0	76
Settlements	-244	-150	-76	0

The rate of loss or gain of carbon is dependent on the type of land use transition (Table 1-23). For transitions where carbon is lost e.g. transition from Grassland to Cropland, a ‘fast’ rate is applied whilst a transition that gains carbon occurs much more slowly. A literature search for information on measured rates of changes of soil carbon due to land use was carried out and ranges of possible times for completion of different transitions were selected, in combination with expert judgement (Table 1-24).

Table 1-23: Rates of change of soil carbon for land use change transitions. (“Fast” & “Slow” refer to 99% of change occurring in times shown in Table 1-24)

		Final			
		Cropland	**Grassland**	**Settlement**	**Forestland**
Initial	**Cropland**		*slow*	*slow*	*slow*
	Grassland	*fast*		*slow*	*slow*
	Settlement	*fast*	*fast*		*slow*
	Forestland	*fast*	*fast*	*fast*	

Table 1-24: Range of times for soil carbon to reach 99% of a new value after a change in land use in England (E), Scotland (S) and Wales (W)

	Low (years)	High (years)
Carbon loss ("fast") E, S, W	50	150
Carbon gain ("slow") E, W	100	300
Carbon gain ("slow") S	300	750

Changes in soil carbon from equilibrium to equilibrium (C_f-C_o) were assumed to fall within ranges based on 2005 database values for each transition and the uncertainty indicated by this source (up to ± 11% of mean). The areas of land use change for each transition were assumed to fall a range of uncertainty of ± 30% of mean.

As regards data quality, land use change activity data are obtained from several sources. The sources for Great Britain have separate good internal consistency, but there is poorer consistency between sources and with the data for Northern Ireland. There may be carry-over effects on emission/removal estimates for the reported years due to the long time response of soil systems.

Data Reporting

The carbon stock change in living biomass due to the increase in non-forest biomass in this category is disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland and entered into Sectoral Background Table 5.B.2 Land Converted to Cropland. The area of land associated with each set of data is also included in Sectoral Background Table 5.B.

Net carbon stock change in soils resulting from land use change is included in Sectoral Background Table 5.B.2 Land converted to Cropland. The data for deforestation is included at the UK level while conversion of Grassland and Settlements to Cropland is disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland and two time periods (pre and post 1990). The areas of land associated with each set of data are also included in this Table.

Planned Improvements

There has been work on improving the spatial and temporal scale of the land use change matrices in non-inventory projects, the results of which will be incorporated into the inventory in due course. As part of the ECOSSE project (funded by the Scottish Executive and Welsh Assembly), detailed regional LUC matrices were developed for Scotland and Wales for 1950-1980 (Smith *et al.* 2007). Similar work is being undertaken for England.

Sampling of the National Soil Inventory between 1978 and 2003 (Bellamy *et al*. 2005) has found large losses of carbon from soils across England and Wales. Work is now underway to assess the relative contributions of land use and management and climate change (and their interaction) to these soil carbon losses. This should produce an estimate of the likely magnitude of past changes in soil organic carbon under different management scenarios and the relative importance of the various drivers of those changes (by 2009). There will then be an assessment as to whether the inventory methodology needs to be adapted in the light of these results. A soil carbon inventory project is underway for Northern Ireland, the results of which will be incorporated into the inventory methodology.

New versions of the GB and Northern Ireland Countryside Surveys are underway, with results due in 2008. The updating of these datasets will allow the extension of the land use change matrices from 1998 to 2007.

Experimental work to detect the effect of cultivation (i.e. Grassland converted to Cropland) on CO_2 and N_2O fluxes and on soil carbon stocks is currently in progress (Work Package 2.6). The results from this work will be used to verify assumptions in the land use change model and to modify the model if necessary.

In the long term, the UK is planning to implement the use of a process-based model for estimating emissions and removals from soils. This method is unlikely to be available for a few years, hence the enhancement of the existing approach over this and the previous inventory.

1.2.3 Grassland (5C)

The Category is disaggregated into *5.C.1 Grassland remaining Grassland* and *5.C.2 Land converted to Grassland*. Category 5.C.1 is disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland.

Two activities are considered for 5.B.1: the impact of peat extraction for horticultural use and carbon dioxide emissions from soil due to agricultural lime application to Grassland (which is also disaggregated into application of Limestone ($CaCO_3$) and Dolomite ($CaMg(CO_3)_2$)). Three activities are considered for 5.B.2: emissions from biomass burning after conversion of Forestland to Grassland, changes in non-forest biomass due to LUC to Grassland and changes in soil carbon stocks due to LUC to Grassland. Conversions from Cropland and Settlements to Grassland are further disaggregated by a) the four geographical areas of England, Scotland, Wales and Northern Ireland and b) two time periods, 1950 – 1990 and 1991 onwards. Biomass burning emissions due to conversion of Forest Land to Grassland is reported at the 5C level for all of the UK in two time periods, 1950-1990 and 1990 onwards.

Grassland remaining Grassland (5.C.1)

Methodology – Application of Lime

See Cropland section for details on agricultural liming on Cropland and Grassland.

Methodology – Peat Extraction

Peat is extracted in the UK for use as either a fuel or in horticulture. Only peat used in horticulture is now reported in the LULUCF sector. Peat used as a fuel is reported in the Energy Sector of the UK Inventory.

Cruickshank & Tomlinson (1997) provide initial estimates of emissions due to peat extraction. Since their work, trends in peat extraction in Scotland and England over the period 1990 to 2005 have been estimated from activity data taken from the UK Minerals Handbook (BGS 2006). In Northern Ireland, no new data on use of peat for horticultural use has been available but a recent survey of extraction for fuel use suggested that there is no significant trend for this purpose. The contribution of emissions due to peat extraction in Northern Ireland is therefore incorporated as constant from 1990 to 2005. Peat extraction is negligible in Wales. Emissions factors for this activity are from Cruickshank & Tomlinson (1997) and are shown in Table 1-25.

Table 1-25: Emission factors for peat extraction

	Emission Factor kg C m^{-3}
Great Britain Horticultural Peat	55.7
Northern Ireland Horticultural Peat	44.1

As the activity data for peat extraction come from a number of sources, only some of which are reliable, the time series consistency is medium.

Data Reporting

The emissions in this Category from agricultural lime application are entered into Sectoral Background Table 5 (IV) Carbon emissions from agricultural lime application. The data are disaggregated by application of limestone and dolomite separately on Grassland (and Cropland).

The emissions in this Category due to peat extraction are entered into Sectoral Background Table 5.C.1 Grassland remaining Grassland, disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland.

Planned Improvements

All emission factors and activity data will be kept under review. A repeat survey of peat extraction (for fuel and horticultural use) in Northern Ireland is underway and due to be completed by 2009 (work package 2.16).

Land converted to Grassland

Methodology - Emissions from biomass burning after conversion of Forest Land to Grassland

Emissions of CO_2, CH_4 and N_2O result from the burning of forest biomass when Forest Land is converted to Grassland. The interpretation of the available data allows the emissions to be disaggregated into deforestation to Grassland and Settlements. Deforestation to Cropland in the UK is negligible.

Levy & Milne (2004) discuss methods for estimating deforestation using a number of data sources. Their approach of combining Forestry Commission felling licence data for rural areas with Ordnance Survey data for non-rural areas was adopted for the inventory.

In Great Britain, some activities that involve tree felling require permission from the Forestry Commission, in the form of a felling licence, or a felling application within the Woodland Grant Scheme. Under the Forestry Act 1967, there is a presumption that the felled areas will be restocked, usually by replanting. Thus, in the 1990s, around 14,000 ha a^{-1} was felled and restocked. However, some licences are granted without the requirement to restock, where there is good reason – so-called unconditional felling licences. Most of these areas are small (1-20 ha), but their summation gives some indication of areas deforested. These areas are not published, but recent figures from the Forestry Commission have been collated. These provide estimates of rural deforestation rates in England for 1990 to 2002 and for GB in 1999 to 2001. The most recent deforestation rate available for rural areas is for 2002 so rates for 2003-2005 were estimated by extrapolating forwards from the rates for 1999 to 2002.

Only local planning authorities hold documentation for allowed felling for urban development, and the need for collation makes estimating the national total difficult. However, in England, the Ordnance Survey (national mapping agency) makes an annual assessment of land use change (Department of Communities and Local Government, 2006, previously the Office of the Deputy Prime Minister) from the data it collects for map updating. Eleven broad land-use categories are defined, with a number of sub-categories. The data for England (1990 to 2005) are available to produce a land-use change matrix, quantifying the transitions between land-use classes. Deforestation rate was calculated as the sum of transitions from all forest classes to all non-forest classes providing estimates on non-rural deforestation.

The rural and non-rural values for England were each scaled up to GB scale, assuming that England accounted for 72 per cent of deforestation, based on the distribution of licensed felling between England and the rest of GB in 1999 to 2001. However, the Ordnance Survey data come from a continuous rolling survey programme, both on the ground and from aerial photography. The changes reported each year may have actually occurred in any of the preceding 1-5 years (the survey frequency varies among areas, and can be up to 10 years for moorland/mountain areas). Consequently, a five-year moving average was applied to the data to smooth out the between-year variation appropriately, to give a suitable estimate with annual resolution. Deforestation is not currently estimated for Northern Ireland. Rural deforestation is assumed to convert the land to Grassland use (reported in Category 5C2) and non-rural deforestation causes conversion to the Settlement land type (reported in 5E2). Information from land use change matrices shows that conversion of forest to cropland is negligible.

Where deforestation occurs it is assumed that 60% of the standing biomass is removed as timber products and the remainder is burnt. The annual area loss rates were used in the method described in the IPCC 1996 guidelines (IPCC 1997c, 1997a, 1997b) to estimate immediate emissions of CO_2, CH_4 and N_2O from this biomass burning. Only immediate losses are considered because sites are normally completely cleared for development, leaving no debris to decay. Changes in stocks of soil carbon after deforestation are included with those due to other land use transitions.

The time series consistency of emissions from this activity is medium given that the two constituent data series are not both available for each year and the values for several years are partially derived from data in one region. Areas deforested in non-rural areas have been revised for each year from 1990 and updated to 2005. Data on rural deforestation is only available up to 2002; therefore areas for 2003-2004 were estimated by extrapolation from earlier years.

Methodology – Changes in Non forest biomass due to land use change to Grassland

This is the annual change in the carbon stock in biomass of vegetation due to all land use change, excluding forests and woodland, to Grassland. See Cropland section for details on non-forest biomass calculations.

Methodology – Changes in soil carbon stocks due to land use change to Grassland

This is the change in soil stocks due to land use change to Grassland. Details of the Methodology are given in the Cropland section.

Data Reporting

Emissions of CO_2, CH_4 and N_2O from biomass burning after conversion of land to Grassland are included in Sectoral Background Table 5 (V) Biomass Burning.

The carbon stock change in living biomass due to the increase in non-forest biomass in this category is disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland and entered into Sectoral Background Table 5.C.2 Land Converted to Grassland. The area of land associated with each set of data is also included in Sectoral Background Table 5.C.

Net carbon stock change in soils resulting from land use change is included in Sectoral Background Table 5.C.2 Land converted to Grassland. The data for deforestation is included at the UK level while conversion of grassland and settlements to Grassland is disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland plus two time periods (pre- and post-1990).

Planned Improvements

All emission factors and activity data will be kept under review. Input data for the deforestation activity remain a problem and work to assimilate relevant data sources for each of the four UK countries is under discussion.

1.2.4 Wetlands (5D)

In the UK, Wetlands will either be saturated land (e.g. bogs, marshes) and, due to the classifications used in the Countryside Survey, will fall into the Grassland category or into open water (e.g. lakes, rivers, reservoirs), which is included in the Other Land category. Sectoral Background Table 5.D. Wetlands is therefore completed with 'IE' (Included Elsewhere).

1.2.5 Settlements (5E)

Category 5.E (Settlements) is disaggregated into *5.E.1 Settlements remaining Settlements* and *5.E.2 Land converted to Settlements*. The area of Settlements in Category 5.E.1 is considered not to have long term changes in carbon stock. Category 5.E.2 is disaggregated into conversions from Forest Land, Cropland and Grassland and these conversions are further disaggregated by a) the four geographical areas of England, Scotland, Wales and Northern Ireland and b) two time periods, 1950 – 1989 and 1990 onwards. Biomass burning emissions due to conversion of Forest Land to Settlements are reported at the 5E level for all of the UK in two time periods, 1950-1989 and 1990 onwards.

Settlements remaining Settlements (5.E.1)

No changes in carbon stocks are reported for land remaining under Settlements. A possible cause of carbon stock change with time would be increasing or decreasing stock of biomass in parks or gardens. This conceptually dealt with under the "changes in stock of non-forest biomass" but further work is required

Data Reporting

Sectoral Background Table 5.E.1 Settlements remaining Settlements is completed with 'NO' (Not Occurring).

Planned Improvements

None are planned at the present time.

Land converted to Settlements

Methodology – Emissions from biomass burning after conversion of Forest Land to Settlements

Emissions of CO_2, CH_4 and N_2O result from the burning of forest biomass when Forest Land is converted to Settlements. The interpretation of the available data allows the emissions to be disaggregated into deforestation to Grassland and Settlements. Deforestation to Cropland is negligible. The methodology is described in the Grassland section.

Methodology - Changes in non-forest biomass due to land use change to Settlements

See the Cropland section for details on non-forest biomass calculations.

Methodology – Changes in soil carbon stocks due to land use change to Settlements

This is the change in soil stocks due to land use change to Grassland. Details of the Methodology are given in the Cropland section.

Data Reporting

Emissions of CO_2, CH_4 and N_2O from biomass burning after conversion of land to Settlements are included in Sectoral Background Table 5 (V) Biomass Burning.

The carbon stock change in living biomass due to the increase in non-forest biomass in this category is disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland and entered into Sectoral Background Table 5.E.2 Land Converted to Settlements. The area of land associated with each set of data is also included in Sectoral Background Table 5.E.

Net carbon stock change in soils resulting from land use change is included in Sectoral Background Table 5.E.2 Land converted to Settlements. The data for deforestation is included at the UK level while conversion of Grassland and Cropland to Settlements is disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland plus two time periods (pre- and post-1990).

Planned Improvements

All emission factors and activity data will be kept under review. Input data for the deforestation activity remain a problem and work to assimilate relevant data sources for each of the four UK countries is under discussion.

1.2.6 Other Land (5F)

No emissions or removals are reported in this category. It is assumed that there are very few areas of land of other types that become bare rock or water bodies, which make up the majority of this type. Therefore Sectoral Background Table 5.F Other Land is completed with 'NO' (Not Occurring).

1.2.7 Other Activities (5G)

Changes in stocks of carbon in harvested wood products (HWP) are reported here.

Methodology

The carbon uptake by the forests planted since 1920 is calculated by a carbon accounting model (C-Flow) as the net change in the pools of carbon in standing trees, litter, soil and products from harvested material for conifer and broadleaf forests. The method is Tier 3, as defined in the GPG LULUCF (IPCC 2003). The model calculates the masses of carbon in the pools of new even-aged plantations that were clear-felled and then replanted at the time of Maximum Area Increment. Only products from UK forests planted since 1920 (i.e. those for which biomass and soil carbon stock changes are reported) are considered at present. It is not considered to be of high priority to consider the decay of imported products etc. as there is no international agreement on a single methodology to be used for reporting.

The C-FLOW model adopts a simple approach to the decay of Harvested Wood Products (HWP). A carbon stock loss of 5% is assumed to be lost immediately at harvest.

Subsequently, the decay time (time to 95% loss of carbon stock) of products is set equal to the rotation time for that species. This approach captures differences in wood product use: fast growing softwoods tend to be used for shorter lived products than slower growing hardwoods. Exponential single decay constants are used for HWP from conifers and broadleaves. Products from thinnings are assumed to have a lifetime (time to 95% loss) of 5 years (half life~0.9 years). The main harvest products have a lifetime equal to rotation length. For conifers this equates to a half life of 14 years and for broadleaves a half life of 21 years. These values fall mid range between those tabled in the LULUCF GPG (IPCC 2003) for paper and sawn products. Limited data were available for the decay of products in the UK when the model was originally developed. The mix of products may be changing in the UK and this could affect the 'true' mean value of product lifetime but there is very limited accurate data on either decay rates or volume statistics for different products. The method used in the UK takes a top-down approach by assuming that the decay of all conifer products and all broadleaf products can be approximated by separate single decay constants. Given the uncertainty on decay of products it is difficult to decide if this is better or worse than a bottom-up approach where each product is given an (uncertain) decay and combined with (uncertain) decay of other products using harvest statistics which are in themselves uncertain.

Calculated in this way, the total wood products pool from UK forests is presently increasing due to continuing expansion in forest area. The time pattern of HWP stock changes is due to the historical pattern of new planting and by the resulting history of production harvesting (and thinning). The stock of carbon in HWP (from UK forests planted since 1920) has been increasing since 1990 but this rate of rise has recently reversed, reflecting a dip in new planting during the 1940s. The stock of carbon in HWP will fall for a few more years but will then begin to rise steeply due to harvesting of the extensive conifer forests planted between 1950 and the late 1980s.

Activity data are obtained consistently from the same national forestry sources, which helps ensure time series consistency of estimated removals.

Data Reporting

Removals of CO_2 associated with harvested wood products are included in Sectoral Report Table 5, as "G Other, Harvested Wood Products".

Planned Improvements

The emission factors and activity data for harvested wood products will be kept under review. Work is currently being undertaken to verify the modelled Harvested Wood Products by comparison with the Forestry Commission Production Forecast.

1.3 Results

Data for the 1990 to 2005 GHG Inventory are presented in Appendices 1 to 4 of this volume. The data for this period (2006 Inventory submission date) are summarised in Table 1-27.
The Appendices contain data in the following formats:
A.1. Summary Tables for 1990 to 2020 in LULUCF GPG Format
A.2. Sectoral Tables for Land Use Change and Forestry Sector submitted as UK 2005 Greenhouse Gas Inventory in LULUCF GPG format
A.3. Sectoral Tables for Land Use Change and Forestry Sector for the Devolved Administration Regions
A.4. Removals and Emissions by post-1990 afforestation and deforestation in the UK

The Sectoral and Background Tables (5, 5A, 5B, 5C, 5D, 5E, 5F, 5(I), 5(II), 5(III), 5(IV) and 5(V)) in the Common Reporting Format of the LULUCF GPG are presented in a companion

Data Table volume on CD for each year 1990 to 2005. Summary data is also provided in the Data Table volume for the Devolved Administration areas of England, Scotland, Wales and Northern Ireland.

All data are reported in Gg (10^9 g) of CO_2 equivalent.

1.3.1 Forest Land (5A)

Forest Land Remaining Forest Land (5.A.1)

Changes in stocks of carbon in Forest Land in the UK that remains Forest Land are assumed to be zero. This category is identified with 820,000 ha of forest that has existed since before 1920 and is also assumed to be in carbon balance because of its age and therefore has zero stock change.

Land converted to Forest Land (5.A.2)

All afforestation (1,652,900 ha) occurring since 1920 is reported in this category. There were no change in the method this year but the estimates were updated with planting statistics for 2005. Net carbon stock changes resulting in atmospheric removals have varied over time: starting from -12,203 Gg in 1990 and reaching a maximum of -16,302 Gg in 2004. The net carbon stock change in 2005 was -15,738 Gg. These changes reflect variation in planting rates in past decades which feed through growth and harvesting to the carbon uptake trends reported here.

1.3.2 Cropland (5B)

Cropland Remaining Cropland (5.B.1)

Changes in carbon stocks resulting from changes in non-forest biomass resulting from yield improvements, application of lime and lowland drainage are reported in this category. There were no changes in the methodology but some revisions of the liming activity data and updating with 2005 data (BGS 2006). Minor revisions in the agricultural census dataset resulted in changes in the allocation of lime to either Cropland or Grassland. Estimated emissions from Cropland have fallen by 11 Gg CO_2 in 2004 compared with the numbers for 2004 in the previous submission (2006 NIR). However, total emissions from the application of lime remain the same, only the allocation to land use has changed.

Overall, the carbon stock changes in this category result in net emissions, which appear to be on a downward trend, starting from 1802 Gg in 1990 (with a peak of 1947 Gg in 1991) to 964 Gg in 2005. This trend is mainly driven by the declining emissions from lowland drainage, which have fallen steadily from 1650 Gg in 1990 to 1173 Gg in 2005. Removals from non-forest biomass yield improvements are constant, and emissions due to liming, although variable, do not show any consistent trend.

Land Converted to Cropland (5.B.2)

Carbon stock changes resulting from changes in non-forest biomass and soil carbon stocks due to land use change to Cropland are reported in this category. There were some minor recalculations from the 2004 inventory. An error in the non-forest biomass matrix for Wales has been corrected. This resulted in a change in emissions of -0.084 Gg CO_2 per year. Although no recalculations were undertaken for changes in soil carbon stocks the nature of Monte Carlo simulation results in minor differences in emissions/removals between years.

Emissions from land converted to Cropland show a small but steady rate of increase, from 14,034 Gg in 1990 to 14,294 Gg in 2005. This trend is due to changes in soil carbon stocks as changes in non-forest biomass stocks occur at a fixed rate.

1.3.3 Grassland (5C)

Grassland Remaining Grassland (5.C.1)

Changes in carbon stocks due to application of lime to Grassland and peat extraction are reported in this category. Estimates of emissions were updated with 2005 data (BGS 2006). Minor revisions in the agricultural census dataset resulted in changes in the allocation of lime to either Cropland or Grassland. Estimated emissions from Grassland have risen by 11 Gg CO_2 in 2004 compared with the numbers for 2004 in the previous submission (2006 NIR). However, total emissions from the application of lime remain the same, only the allocation to land use has changed.

Emissions from this category are variable over the time period, starting at 1,028 Gg in 1990, with a peak of 1,256 Gg in 1995, and then falling away to 564 Gg in 2002, with an emission of 692 Gg in 2005. Both of the carbon stock changes which contribute to this category are variable over time, but the downward trend between 1995 and 2002 seems to be mainly due to a reduction in emissions from liming of Grassland.

Land Converted to Grassland (5.C.2)

Changes in carbon stocks due to emissions from biomass burning after conversion of Forest Land to Grassland and changes in non-forest biomass and soil carbon stocks due to land use change to Grassland are reported in this category. Data on rural deforestation (Forest Land converted to Grassland) is only available up to 2002; therefore areas for 2003-2005 were estimated by extrapolation from earlier years. The revision of the deforestation dataset also resulted in a re-allocation of areas in the land use change matrix, producing changes in emission/removal estimates from those in the 2004 National Inventory Report. The nature of Monte Carlo simulation also results in minor differences in emissions/removals between years. There was a change of -32 Gg CO_2 in 2004 (compared with the estimate for 2004 in the 2006 NIR).

Overall, this category results in a net removal from the atmosphere, which has increased over time, from -7,228 Gg in 1990 to 8,627 Gg in 2005. This trend is entirely due to changes in soil carbon stocks from land converted to Grassland, as changes in non-forest biomass stocks are a small and constant removal (-198 Gg a^{-1}), and changes due to biomass burning after deforestation are an equally small although variable emission (30-180 Gg a^{-1}).

1.3.4 Settlements (5E)

Settlements Remaining Settlements (5.E.1)

No changes in carbon stocks are reported in this category.

Land Converted to Settlements (5.E.2)

Changes in carbon stocks due to emissions from biomass burning after conversion of Forest Land to Settlements and changes in non-forest biomass and soil carbon stocks due to land use change to Settlements are reported in this category. There were some revisions of activity data for this category. The data on the area of deforestation in non-rural areas have been revised for each year from 1990-2003. A five-year moving average (a three-year moving average was previously used) has been applied on the recommendation of the data suppliers (Department of Communities and Local Government). The area of deforestation in 2004 and 2005 has been estimated by extrapolation from earlier years. These revisions have resulted in a change of 31 Gg CO_2 for 2004 compared with the 2004 estimate submitted in the 2006 NIR. The revision of the deforestation dataset resulted in a re-allocation of areas in the land use change matrix, producing a change of 11 Gg CO_2 in emission/removal estimates in 2004 from those in the 2006 NIR. The nature of Monte Carlo simulation also results in minor differences in emissions/removals between years.

Overall, this category results in a net emission to the atmosphere, although this is slowly decreasing over time, from 6,904 Gg in 1990 to 6,262 Gg in 2005. This trend is due to changes in soil carbon stocks from land converted to Settlements, as removals due to biomass changes and emissions due to biomass burning after deforestation are both small (-50 and 53-122 Gg a^{-1} respectively).

1.3.5 Other Activities (5G)

Changes in carbon stocks in this category result from changes in harvested wood products. The estimates of emissions/removals were updated with planting statistics for 2005. This category produced a net removal from the atmosphere in 1990 of -1,456 Gg, decreasing to -633 Gg in 1994, then rising to -1,306 Gg in 1998, before rapidly decreasing (and becoming a net emission in 2002) to a net emission of 619 Gg in 2004. The net emission in 2005 was 96 Gg. This variability is driven by forest planting and harvesting patterns in previous decades (see Thomson in the 2006 annual report). The current net emission from HWP results from the reduced levels of new planting during the 1940s, and we would expect this activity to become a net sink from 2006 onwards.

1.3.6 Net UK Emissions/Removals

The picture of net emissions/removals from the Land Use Change and Forestry Sector in the UK has not changed significantly from the previous Inventory, as the data revisions that have been made are relatively minor. The net emission in 1990 is calculated to be slightly smaller than that calculated in the 2004 inventory (2,882 Gg rather than 2,915 Gg). England is a net emitter between 1990 and 2005 (although on a downwards trend), while Scotland and Northern Ireland are net removers (with removals increasing 1990-2005). Wales has a small net removal but does not have the strong trend shown in the other countries. The net emissions for the UK follow a downward trend, reaching zero in 1998 and continuing to a net removal of -2,056 Gg in 2005.

1.4 LUCF GHG Data on basis of IPCC 1996 Guidelines

The structure of this report and the 2007 submissions of the National Inventory Report and the main submission of CRF Tables, are based on the Categories of the Common Reporting Format tables agreed at the 9th Conference of Parties to the UNFCCC and contained in FCCC/SBSTA/2004/8, also referred to as the IPCC 2003 Good Practice Guidelines CRF categories. Tables showing the relationship between the previous IPCC 1996 categories and the GPG categories can be found in the 2006 project report and the 1990-2004 National Inventory Report. The reported totals for emissions and removals for the LULUCF Sector are the same in either format.

1.5 Uncertainties

Approximate uncertainties for different activities used in the IPCC GPG reporting structure are shown in Table 1-26. An uncertainty of 20% was estimated for CH_4 and N_2O emissions from biomass burning after deforestation (categories 5C2 and 5E2). A full analysis of uncertainties is planned for future versions of the Inventory.

Table 1-26: Approximate uncertainty of estimates of emissions/removals for LULUCF GPG categories

IPCC Source Category	Uncertainty in 1990 CO_2 emissions/removals, %	Uncertainty in 2005 CO_2 emissions/removals, %
5A Forest Land	25	25
5B Cropland	45	50
5C Grassland	70	55
5D Wetland	-	-
5E Settlements	35	50
5F Other Land	-	-
5G Other Activities	30	30

1.6 LULUCF reporting for the UK's Overseas Territories and Crown Dependencies

The UK has now been asked to estimate LULUCF emissions/removals from the UK's Overseas Territories and Crown Dependencies who have joined the UK's instruments of ratification for the UNFCCC and the Kyoto Protocol. These Overseas Territories are Bermuda, the Cayman Islands, the Falkland Islands, Montserrat, the British Virgin Islands and Gibraltar. The Crown Dependencies are Jersey, Guernsey and the Isle of Man. A Masters student (Kate Ruddock, University of Edinburgh) is currently working on a project to assimilate data and construct inventories for these territories. This project will be completed by the end of August 2007 and the results will be reported in next year's annual report and National Inventory Report.

Table 1-27: Emissions and removals in categories within the Land Use Change and Forestry Sector as reported in the format used for the UNFCCC Common Reporting Format defined by the IPCC LULUCF Good Practice Guidance.

Gg CO_2/year		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
5	NET	**2882**	**2755**	**2251**	**1068**	**863**	**992**	**850**	**502**	**-53**	**-267**	**-449**	**-603**	**-1124**	**-1181**	**-1935**	**-2056**
5A	**Forest-Land**	**-12203**	**-12715**	**-13340**	**-13714**	**-14193**	**-13948**	**-13720**	**-13512**	**-13406**	**-13504**	**-13805**	**-14348**	**-15045**	**-15646**	**-16302**	**-15738**
5A1	*Forest-Land remaining*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*		*0*
5A2	*Land converted to Forest-*	*-12203*	*-12715*	*-13340*	*-13714*	*-14193*	*-13948*	*-13720*	*-13512*	*-13406*	*-13504*	*-13805*	*-14348*	*-15045*	*-15646*	*-16302*	*-15738*
5B	**Cropland**	**15836**	**15996**	**16001**	**15577**	**15631**	**15771**	**15803**	**15543**	**15428**	**15329**	**15339**	**15287**	**15313**	**15384**	**15316**	**15258**
5B1	*Cropland remaining Cropland*	*1802*	*1947*	*1938*	*1498*	*1535*	*1658*	*1672*	*1395*	*1262*	*1145*	*1136*	*1065*	*1072*	*1126*	*1039*	*964*
5B2	*Land converted to Cropland*	*14034*	*14048*	*14063*	*14079*	*14096*	*14113*	*14131*	*14148*	*14166*	*14185*	*14203*	*14222*	*14240*	*14258*	*14276*	*14294*
5B (liming)	*Liming of Cropland*	*792*	*974*	*1002*	*598*	*672*	*831*	*882*	*642*	*546*	*465*	*493*	*444*	*473*	*549*	*484*	*431*
5C	**Grassland**	**-6200**	**-6152**	**-6261**	**-6671**	**-6614**	**-6541**	**-6789**	**-6893**	**-7291**	**-7283**	**-7446**	**-7470**	**-7766**	**-7559**	**-7858**	**-7934**
5C1	*Grassland remaining*	*1028*	*1194*	*1198*	*915*	*1082*	*1256*	*1108*	*1125*	*827*	*854*	*728*	*747*	*564*	*872*	*685*	*692*
5C2	*Land converted to Grassland*	*-7228*	*-7346*	*-7458*	*-7585*	*-7695*	*-7797*	*-7897*	*-8017*	*-8118*	*-8136*	*-8174*	*-8216*	*-8330*	*-8431*	*-8543*	*-8627*
5C (liming)	*Liming of Grassland*	*638*	*798*	*808*	*532*	*598*	*698*	*633*	*705*	*512*	*422*	*301*	*281*	*265*	*369*	*330*	*288*
5D	**Wetland**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**
5D1	*Wetland remaining Wetland*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*
5D2	*Land converted to Wetland*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*
5E	**Settlements**	**6904**	**6836**	**6770**	**6718**	**6671**	**6610**	**6578**	**6560**	**6521**	**6458**	**6413**	**6374**	**6327**	**6302**	**6291**	**6262**
5E1	*Settlements remaining*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
5E2	*Land converted to Settlements*	*6904*	*6836*	*6770*	*6718*	*6671*	*6610*	*6578*	*6560*	*6521*	*6458*	*6413*	*6374*	*6327*	*6302*	*6291*	*6262*
5F	**Other-Land**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**		**0**
5F1	*Other-Land remaining Other-*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*		*0*
5F2	*Land converted to Other-Land*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*		*0*
5G	**Other activities**	**-1456**	**-1210**	**-920**	**-842**	**-633**	**-900**	**-1021**	**-1197**	**-1306**	**-1268**	**-950**	**-445**	**47**	**337**		**619**
5G1	*Harvested Wood Products*	*-1456*	*-1210*	*-920*	*-842*	*-633*	*-900*	*-1021*	*-1197*	*-1306*	*-1268*	*-950*	*-445*	*47*	*337*	*619*	*96*
5B2, 5C2, 5E2	**Biomass burning Gg CH_4 a^{-1}**	*0.592*	*0.559*	*0.531*	*0.473*	*0.485*	*0.449*	*0.521*	*0.544*	*0.545*	*0.775*	*0.978*	*1.174*	*1.006*	*0.972*	*0.933*	*0.925*
5B2, 5C2, 5E2	**Biomass burning Gg N_2O a^{-1}**	*0.0041*	*0.0038*	*0.0037*	*0.0032*	*0.0033*	*0.0031*	*0.0036*	*0.0037*	*0.0037*	*0.0053*	*0.0067*	*0.0081*	*0.0069*	*0.0067*	*0.0064*	*0.0064*

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