Data Analysis and Estimation of Greenhouse Gas Emissions and Removal for the IPCC Sector Land Use, Land-Use Change and Forestry Sectors in Ireland

Environmental Research Centre Report

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ACKNOWLEDGEMENT

This report has been prepared as part of the Environmental Research Technological Development and Innovation Programme under the Productive Sector Operational Programme 2000–2006. The programme is financed by the Irish Government under the National Development Plan 2000–2006. It is administered on behalf of the Department of the Environment, Heritage and Local Government by the Environmental Protection Agency which has the statutory function of co-ordinating and promoting environmental research. The EPA research programme for the period 2007–2013 is entitled Science, Technology, Research and Innovation for the Environment (STRIVE).

ENVIRONMENTAL RESEARCH CENTRE PROGRAMME 2000–2006

Published by the Environmental Protection Agency, Ireland

PRINTED ON RECYCLED PAPER

ISBN: 1-84095-246-6

Price: €15

12/07/300

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Executive Summary

Emissions linked to land use, land-use change and forestry represent up to 30% of global greenhouse gas (GHG) emissions. Deforestation has a significant impact on these emissions. Increased afforestation is regarded as having significant potential to act as a sink for atmospheric carbon dioxide (CO_2). With appropriate management, Ireland's land resources may make an important contribution to CO_2 sequestration. However, the development of management strategies needs to be based on sound scientific understanding of this area.

This document presents the detailed methods employed to generate an estimate of the exchange of GHGs to the atmosphere due to land use and land-use change in Ireland, in compliance with UN Convention reporting requirements. The document is especially concerned with the methods employed in the completion of the National Inventory Report (NIR) 2006 for Ireland.

The estimated GHG emissions sinks associated with crop and grass land-use types and changes to these over the period are based on the procedures outlined in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC GPG) for Tier 1 estimation of the GHG exchange to the atmosphere*.* This is the default used in the absence of national data and provides a basis for further development of this analysis.

The carbon fluxes linked to forestry biomass and forestry dead organic matter (DOM) are based on analysis based on research carried out by COFORD, the forest research agency. These are estimated using more sophisticated methods (the CARBWARE model), as part of the COFORD CARBiFOR project, described elsewhere (http://www.coford.ie/iopen24/pub/defaultarticle.php?cArticlePath=196_266_227).

The analysis shows that GHG emissions are associated with:

- Grasslands, due to lime spreading, biomass loss, soil disturbance and changes in grassland management
- Cropland, due to soil disturbance and biomass loss
- Forestry biomass loss, DOM, and soil disturbance
- Settlements change in biomass
- Wetlands biomass loss and soil disturbance
- Others biomass loss, soil disturbance and changes in management.

Forestry biomass is the primary sink for carbon.

The default analysis has highlighted issues with respect to liming of land which is a significant source of CO_2.

The default analysis forms a basis for incorporation of outcomes from current research projects in order to provide more scientifically robust analysis.

Except where stated, emissions are based on the default emission factors and carbon stocks published in the IPCC GPG.

1 Introduction and Background

Global emissions are of the order of 30 billion tonnes of carbon dioxide (CO_2) per annum. The primary anthropogenic sources of CO_2 are fossil fuel combustion and land-use changes, principally deforestation. Global atmospheric CO_2 concentrations are now higher than they have been for at least 250,000 years and potentially for a significantly longer period (IPCC, 2001).

The increased levels of atmospheric greenhouse gases (GHGs) have raised considerable scientific concern in relation to enhanced global warming and resultant climatic change. These concerns have resulted in the establishment of the UN Framework Convention on Climate Change (UNFCCC) which aims to stabilise atmospheric GHG concentrations at a level that would prevent dangerous climate change. The Kyoto Protocol, agreed in 1996, was a further step in this process which aimed to limit emissions of specified GHGs to 5% below the 1990 level over the 2008–2012 period.

Ireland has ratified the Kyoto Protocol and published the National Climate Change Strategy (NCCS) in 2001. This provided a pathway to achieve the national Kyoto Protocol target under the EU burden-sharing agreement, which was to limit national emissions of GHGs to 13% above 1990 levels. The NCCS aimed to remove CO_2 from the atmosphere through the use of carbon sinks such as forestry. This is referred to as carbon sequestration.

Parties to the Kyoto Protocol can offset emissions of CO_2 by development of sinks, i.e. in the management of forests, soils and vegetation as outlined in Article 3 of the Kyoto Protocol. This covers activities related to afforestation, reforestation, cropland management, grassland management and revegetation.

Detailed rules and guidelines for estimating changes in carbon stocks and calculating emissions under Articles 3.3 (afforestation and reforestation) and 3.4 (forest management) are set out in the Marrakesh Accords in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1997).

The estimation of GHG emissions and sinks for activities within the land use and land-use change and forestry (LULUCF) sector for reporting purposes poses a number of challenges. LULUCF is primarily concerned with the effects of land use on carbon stocks stored in the soil, biomass and dead organic matter (DOM), these latter two being principally related to forestry. Nitrous oxide (N_2O) and methane emissions from soils which can be directly linked to anthropogenic management of the soil should also be estimated, excluding activities already accounted for within another sector, such as agriculture.

The Intergovernmental Panel on Climate Change (IPCC) *Good Practice Guidelines* (GPG) identifies three levels or tiers of complexity that can be used in making the GHG emissions calculation. Emissions inventory data are reported to the UNFCCC on an annual basis.

1.1 GPG Tiers

The IPCC GPG provides a standard or default method to estimate GHG emissions from various sectors and activities. Tier 1 is based on default values derived from international research. The highest tier, Tier 3, is based on advanced scientific analysis. The UNFCCC and IPCC GPG recommend progression towards a higher tier methodology for all sectors and activities, with priority given to key sources.

1. Tier 1 analysis presents a relatively simple model of GHG emissions and sinks. As far as possible, Tier 1 methods depend on activity data already commonplace in most countries, which have been compiled for other reasons. Tier 1 emission factors can have large uncertainty associated with them. Tier 1 requires that activity data be available on a spatial scale which reflects the climatic zones within a country.

2. Tier 2 methods follow the same model framework as Tier 1, using the same (or slightly modified) relationships between activity data and emissions, but using emission factors that more closely reflect local conditions. Tier 2 emissions factors should be based on well-documented and peer-reviewed research, and should result in a demonstrably better estimate of GHG activity, particularly in terms of reducing uncertainty. The Tier 2 method can also subdivide the default activity categories beyond the

relatively coarse classifications used in the Tier 1 methods.

3. Tier 3 methods are those that are based on scientific research relevant to that country. The models involved are highly country specific, adapted in fundamental ways to yield a more accurate representation of the GHG activity within the country. Comprehensive peer review of the models employed in Tier 3 is required.

1.2 Ireland and IPCC GPG Climate Zones

The IPCC GPG divides the world into a number of broad climate zones. The reference map in the GPG shows Ireland in the cold temperate wet zone. The annual mean temperature range for this zone is 0–10°C and a moisture regime where precipitation is greater than potential evapotranspiration (PET).

The annual mean temperature in Ireland is 9°C, with summer means of about 15–17°C and winter means of 5–8°C. Mean annual precipitation is between 700 mm in the east and 1,250 mm in the west. In the west rainfall exceeds PET for 11 months of the year, and by 750 mm. In the east rainfall exceeds PET by 250 mm and for 9 months (Cross, 2006). Therefore, Ireland fits comfortably within the IPCC climate zone. However, it should be noted that the Irish climate displays significantly less extremes in temperature and is notably wetter than other regions in the same broad climate zone.

1.3 Concepts of Land Use and Land-Use Change

The total area of the country must be accounted for within LULUCF, this includes both exploited and unexploited lands (wildernesses). Wilderness is unexploited, and any GHG activity therein is considered to be natural and is not considered as part of the inventory of GHG emissions due to anthropogenic activities. This does not mean that such soils are not subject to changes caused by factors such as climate change.

In general, land use is long term, with consistency in usage over decades. This long-term land usage is termed as land 'remaining' in a given land-use class. For example, 'Cropland remaining Cropland' are those land areas that have been given over to crop cultivation for more than 20 years. The analysis of these lands focuses on anthropogenic land management practices that change the carbon stock over long time periods, e.g. loss of carbon due to soil tillage. However, short-term changes in land-management practices may also influence the carbon profile, e.g. a change to intensify production, reseeding and fertiliser use. Such activities impact on soil organic carbon (SOC) and the biomass.

When land-use changes, the land is said to be 'in transition'. The lands in transition are assumed to exhibit different carbon exchange characteristics than lands that remain in the same land use. The timescale over which a newly converted land parcel is said to be in transition is an important parameter in the estimation of LULUCF carbon changes. Conversion to a new land use generally involves considerable disturbance of the existing land parcel. The transition period is an expert estimate of the time for a land parcel to achieve a carbon profile that is similar to the lands already long established within this land-use class.

1.4 Area of Ireland Land-Use Types

The Central Statistic Office (CSO) is the official source for national data and it provides data on areas of grasslands and croplands in agricultural use and forestry figures.

The Ordnance Survey of Ireland (OSi) estimates the total land area of Ireland to be 7.028 Mha. An estimate based on the CORINE 1990 database is 7.11 Mha, but includes estuarine, inter-tidal flats and other flooded coastal areas. The CORINE estimate of land and freshwater areas in Ireland is 7.03 Mha and is consistent with the OSi area estimates (OSi, 2002: http://www.osi.ie/mapping/FAQ/areaWaterLand.shtml).

The total land area is assumed to remain constant over the period being considered, i.e. it assumes no loss of land to the sea, or reclamation of land. A comparison of CORINE 1990 and CORINE 2000 suggests an increased area of 41 ha. Therefore, this assumption of constant land area is reasonable.

The IPCC GPG for LULUCF recognises six generic land-use types, i.e. Forest Land, Grassland, Cropland, Settlements, Wetlands and Other Land.

Land-cover data for these areas based on CORINE 1990 are shown in Table 1.1. Grassland is the largest use type. Wetlands, Forest Land and Cropland comprise smaller but significant areas.

Table 1.1. Comparison of IPCC land-use areas according to CORINE 1990.

	CORINE 1990 (ha)	% CORINE	LULUCF 1990 (ha)	% LULUCF
Forest Land	304,387	4	370,160	5
Grassland	4,212,171	59	4,040,599	57
Cropland	679,518	10	394,800	6
Settlements	97,777	1	98,105	1
Wetlands and Peatlands[1]	1,267,245	18	1,228,661 73,980	17
Other Land	549,889	8	905,481	13

[1]Wetlands have been divided into Peatlands and Wetlands. Peatlands are those lands exploited for the purposes of peat extraction. Wetlands are considered to be natural wetlands.

The CORINE analysis is known to give rise to significant anomalies (EPA, 2004: http://www.epa.ie/OurEnvironment/Land/CorineLandCover/), especially in fragmented landscapes. Its main value is as an indicator of spatial distribution of land-use cover in relation to underlying soil types. Appendix A gives the relationships between CORINE class and LULUCF land-use category used in this analysis.

The National Inventory Report (NIR) requires annual tracking of land-use change from the 1990 base year in order to estimate annual GHG exchange to the atmosphere.

1.5 IPCC Soil Types

In general, any activity that disturbs the soil will induce a release of carbon from the soil to the atmosphere. The IPCC GPG identifies six soil types, i.e. High Activity Clays Low Activity Clay, Sandy Soils, Peaty/Humic Soils, Volcanic Soils and Wetlands (Fig. 1.1).

Soils in Ireland are carbon rich, with a high percentage of wet/peatlands soils. Figure 1.2 shows the distribution of total carbon stocks as derived by Tomlinson (2005). The distribution shows the occurrence of major wet/peatland through out the country.

These wetland areas are not included in the consideration of LULUCF activities unless changed by anthropogenic activities during the period under consideration.

The relative abundance of IPCC soil types in Ireland is summarised in Table 1.2. These data are based in this analysis on the General Soil Association Map for Ireland (GSM) of Gardiner and Radford (1980a,b), shown in Fig. 1.3, and from Tomlinson (2005). A detailed breakdown of the IPCC soil class relationship is provided in Appendix A

Table 1.2. Proportion of total land area with IPCC soil classes.

IPCC soil type	% Sum
High Activity Clay	5.7
Low Activity Clay	60.9
Sandy Soils	4.6
Peaty/Humic Soils	9.6
Peat	16.9
NA	1.6
Unclassified	0.7
Sum	**100.0**

1.6 IPCC Carbon Pools

The IPCC GPG identifies five distinct carbon pools within any given land-use category. These are:

1. Above-ground living biomass
2. Below-ground living biomass
3. Above-ground dead organic matter
4. Below-ground dead organic matter
5. Soil organic carbon.

Living biomass pools are closely linked and can be considered together in the Tier 1 analysis. The same is true for the DOM pools, as is illustrated in Table 1.3.

1.7 Land-Use and Management Factors

Land management can have a significant influence on the soil organic component, living biomass and DOM in a system. The IPCC GPG incorporates farm management

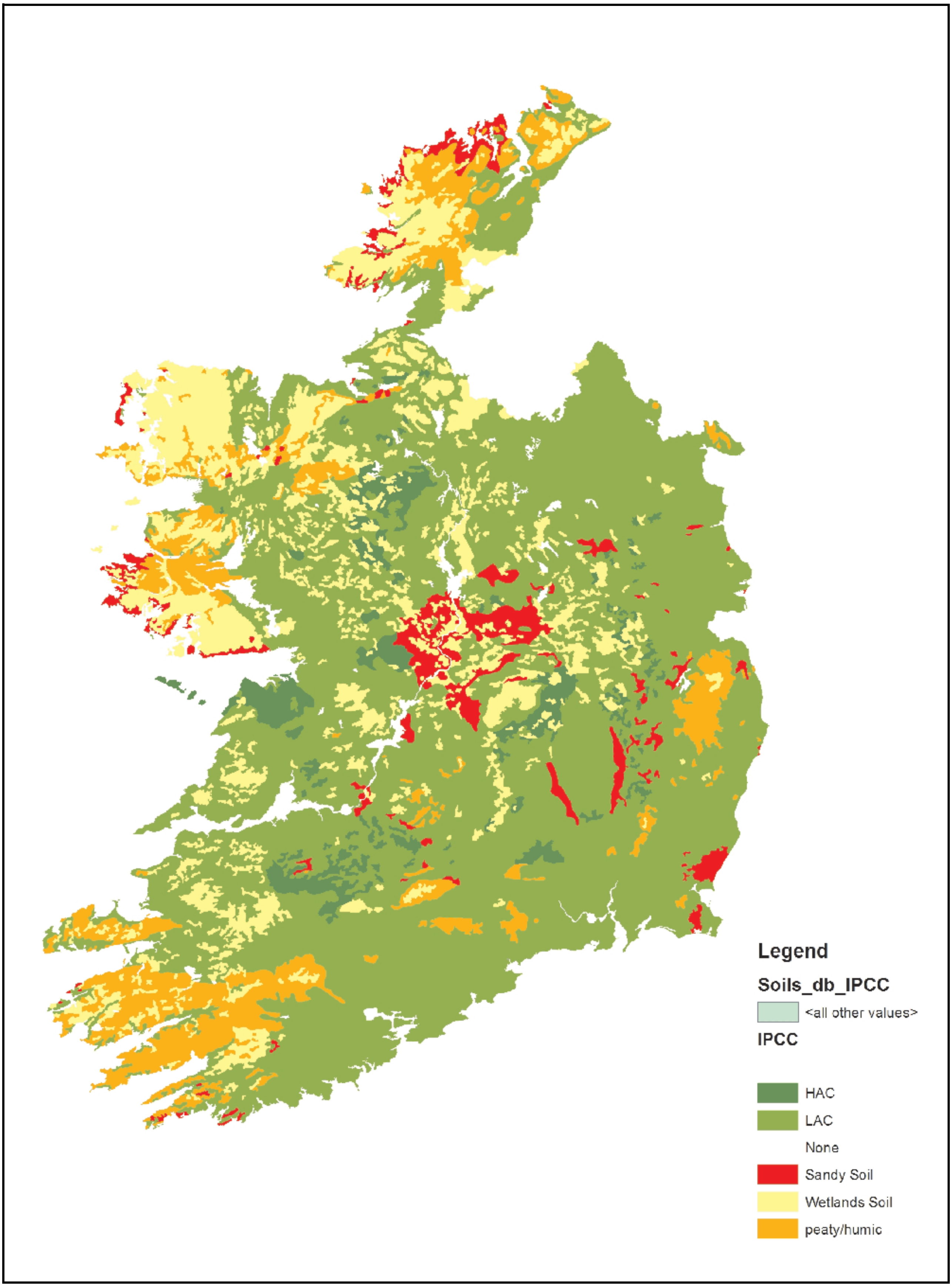


Figure 1.1. IPCC soil type map after Tomlinson (2005).

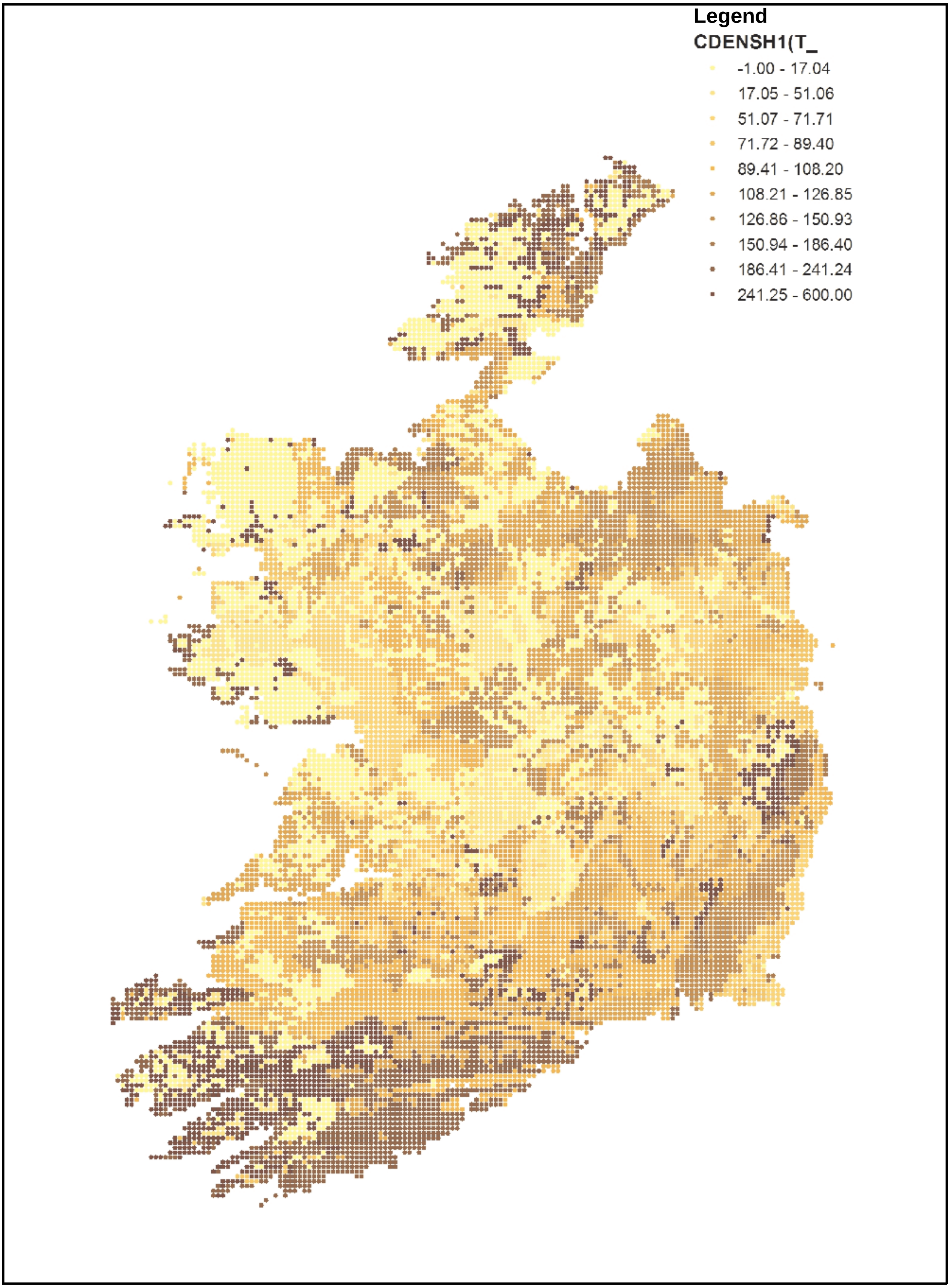


Figure 1.2. Distribution of total carbon stocks, Tomlinson (2005).

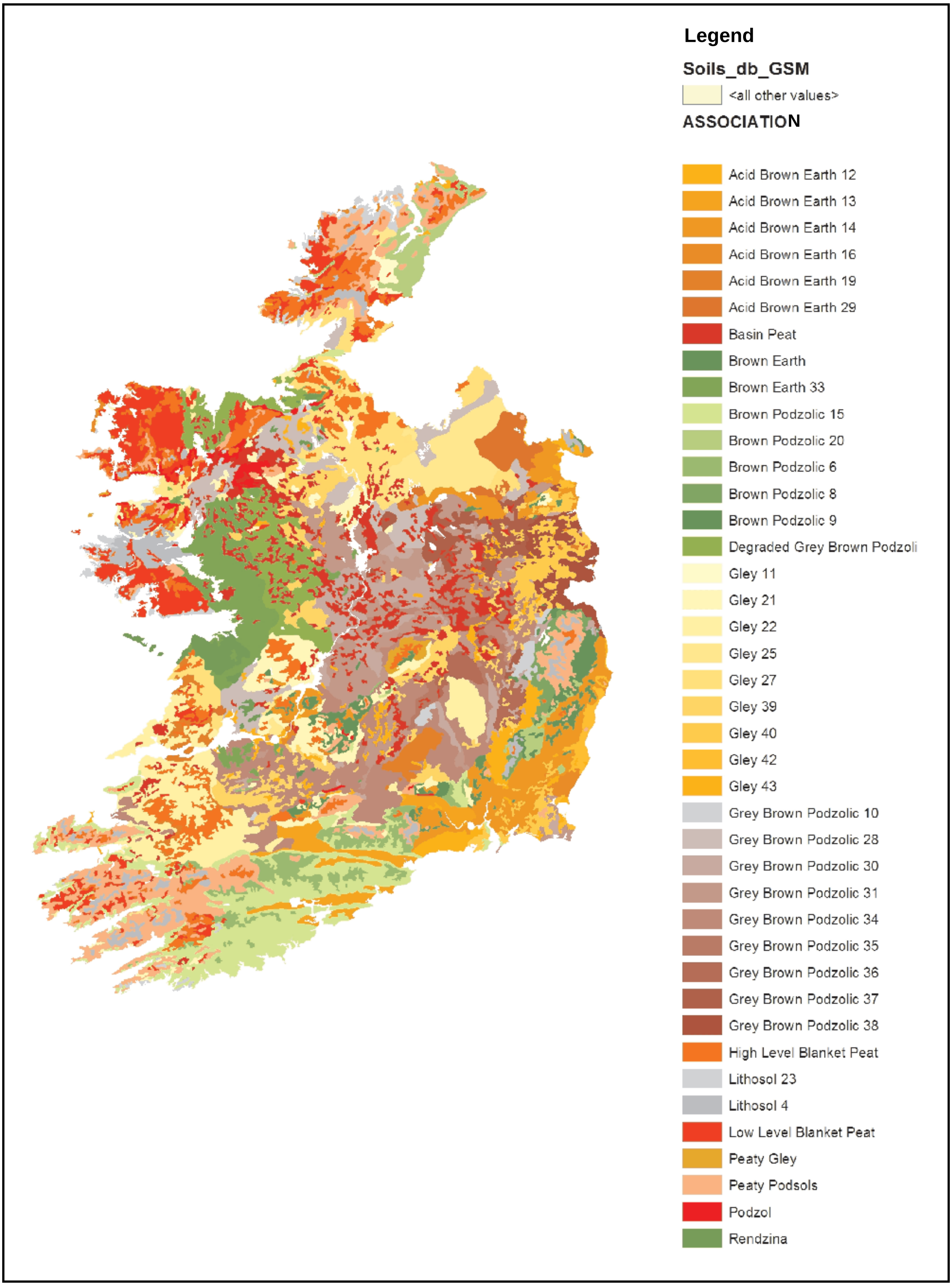


Figure 1.3. The Ireland: General Soil Map, originally produced by Gardiner and Radford (1973).

Table 1.3. Hierarchy of carbon pools in LULUCF-tiered methodology

Tier 1	Living biomass		Dead organic matter		Soil
Tier 2	Above-ground living biomass	Below-ground living biomass	Above-ground DOM	Below-ground DOM	Soil organic carbon

into the Tier 1 soil model using a system of management factors, referred to as F factors as follows:

- F_{LU} is the land-use category
- F_{MG} is the basic farm management strategy
- F_I is an additional factor that may be applied if additional farm management inputs beyond 'normal' practice are utilised.

These factors are used to estimate the carbon content of soils under long-term management by reference to a natural state, SOC_{Ref}. This formulation is shown in Eqn 1.1.

$$SOC = SOC_{Ref} \times F_{LU} \times F_{MG} \times F_I \qquad (1.1)$$

The IPCC GPG default SOC_{Ref} values for Irish conditions, i.e. a cool, temperate, moist climate regime, are listed in Table 1.4.

The application of the IPCC process for LULUCF is developed using best available national data for living biomass, DOM and soil carbon for the six IPCC land-use categories, i.e.

- The land areas for each LU category
- The land areas that have been converted to a different LU since the previous analysis
- The timing and timescale over which conversion, or transition, to the new LU takes place
- The previous LU and land management of these converted areas
- The relationship between LULUCF and soil type.

The sources for these data are listed in Table 1.5.

The CORINE and LPIS databases were used to infer the previous land use for areas in land-use transition. The

Table 1.4. IPCC default soil organic carbon stocks in Ireland's climate zone (extract from the IPCC GPG Table 3.2.4). Default reference (under native vegetation) soil organic carbon stocks (SOC_{Ref}) (t C/ha for 0–30 cm depth).

Climate zone	HAC soils	LAC soils	Sandy soils	Spodic soils	Volcanic soils[1]	Wetlands soils
Cold temperate moist	95	85	71	115	130	87

HAC, High Activity Clay; LAC, Low Activity Clay.
[1]There are no volcanic soil areas occurring in Ireland at the resolution of the soil association map used in this analysis.

Table 1.5. Summary of data sources used for LULUCF GHG emissions estimate.

Land-use type	Data sources	Analysis	Comments
Forest Land	Forest Service, COFORD, Coillte, FIPS and CORINE	Soil	Significant GIS
Grassland	CORINE, CSO, LPIS, IBEC	Biomass and soil	Some GIS
Cropland	CSO, LPIS	Biomass and soil	Some GIS
Wetlands	Bord na Móna	Biomass and soil	No GIS
Settlements	CSO, NRA, CORINE, DEHLG, ESB	Biomass	Little GIS
Other Land	CORINE	Biomass and soil	Little GIS

FIPS: Forest Inventory and Planning System.
LPIS: Land Parcel Information System, maintained by Department of Agriculture and Food.
CSO: Central Statistics Office.
IBEC: Irish Business and Employers Confederation.
NRA: National Roads Authority.
DEHLG: Department of the Environment, Heritage and Local Government.
ESB: Electricity Supply Board.

GSM/IPCC soil map was used to determine the soil type. Where an inconsistency arose, the previous land-use type was set to grassland.

Table 1.6 shows conversions between different land uses. Transitions that are applicable for Ireland are in darker shading. Table 1.7 is a supplementary outline of how each transition was treated in the present estimate of carbon change due to LULUCF.

Soil type has a significant influence on the dynamics of carbon exchange and land use. It is not currently feasible to establish the underlying soil type of every land parcel. Instead the typical soil types have been associated with each land use. The resultant analysis is discussed in the following chapters in the context of each land-use category.

Table 1.6. Matrix of possible land-use change within LULUC

	Forest Land	Grassland	Cropland	Wetlands	Settlements	Other Land
Current land use						
	Forest Land remaining Forest Land	Grassland remaining Grassland	Cropland remaining Cropland	Wetlands remaining Wetlands	Settlements remaining Settlements	Other Land remaining Other Land
Previous land use						
Forest Land		Forest Land in transition to Grassland	Forest Land in transition to Cropland	Forest Land in transition to Wetlands	Forest Land in transition to Settlements	Forest Land in transition to Other Land
Grassland	Grassland in transition to Forest Land		Grassland in transition to Cropland	Grassland in transition to Wetlands	Grassland in transition to Settlements	Grassland in transition to Other Land
Cropland	Cropland in transition to Forest Land	Cropland in transition to Grassland		Cropland in transition to Wetlands	Cropland in transition to Settlements	Cropland in transition to Other Land
Wetlands	Wetlands in transition to Forest Land	Wetlands in transition to Grassland	Wetlands in transition to Cropland		Wetlands in transition to Settlements	Wetlands in transition to Other Land
Settlements	Settlements in transition to Forest Land	Settlements in transition to Grassland	Settlements in transition to Cropland	Settlements in transition to Wetlands		Settlements in transition to Other Land
Other Land	Other Land in transition to Forest Land	Other Land in transition to Grassland	Other Land in transition to Cropland	Other Land in transition to Wetlands	Other Land in transition to Settlements	

Darker shaded cells indicate those changes relevant to this analysis.

Table 1.7. Summary of LULUCF transitions and carbon pools contributing to the total carbon change estimate.

Current land use	Previous land use		Living biomass	DOM	Soil carbon
Forest Land		Forest Land remaining Forest Land	Yes	Yes	Yes
Forest Land	Grassland	Grassland in transition to Forest Land	Yes	Yes	Yes
Forest Land	Cropland	Cropland in transition to Forest Land	Yes	Yes	Yes
Forest Land	Wetlands	Wetlands in transition to Forest Land	Yes	Yes	Yes
Forest Land	Settlements	Settlements in transition to Forest Land	NA	NA	NA
Forest Land	Other Land	Other Land in transition to Forest Land	Yes	Yes	Yes
Grassland		Grassland remaining Grassland	NA	NA	Yes
Grassland	Forest Land	Forest Land in transition to Grassland	NA	NA	NA
Grassland	Cropland	Cropland in transition to Grassland	Yes	Negligible	Yes
Grassland	Wetlands	Wetlands in transition to Grassland	Yes	Negligible	Yes
Grassland	Settlements	Settlements in transition to Grassland	NA	NA	NA
Grassland	Other Land	Other Land in transition to Grassland	Yes	Negligible	Yes
Cropland		Cropland remaining Cropland	NA	NA	Yes
Cropland	Forest Land	Forest Land in transition to Cropland	NA	NA	NA
Cropland	Grassland	Grassland in transition to Cropland	Yes	Negligible	Yes
Cropland	Wetlands	Wetlands in transition to Cropland	NA	NA	NA
Cropland	Settlements	Settlements in transition to Cropland	NA	NA	NA
Cropland	Other Land	Other Land in transition to Cropland	NA	NA	NA
Wetlands		Wetland remaining Wetland	Yes	No	Yes
Wetlands	Forest Land	Forest Land in transition to Wetland	NA	NA	NA
Wetlands	Grassland	Grassland in transition to Wetland	NA	NA	NA
Wetlands	Cropland	Cropland in transition to Wetland	NA	NA	NA
Wetlands	Settlements	Settlements in transition to Wetland	NA	NA	NA
Wetlands	Other Land	Other Land in transition to Wetlands	NA	NA	NA
Settlements		Settlements remaining Settlements	No	Negligible	Negligible
Settlements	Forest Land	Forest Land in transition to Settlements	Yes	Negligible	Negligible
Settlements	Grassland	Grassland in transition to Settlements	Yes	Negligible	Negligible
Settlements	Cropland	Cropland in transition to Settlements	Yes	Negligible	Negligible
Settlements	Wetlands	Wetlands in transition to Settlements	Yes	Negligible	Negligible
Settlements	Other Land	Other Land in transition to Settlements	Yes	Negligible	Negligible
Other Land		Other Land remaining Other Land	Not valid	Not valid	Not valid
Other Land	Forest Land	Forest Land in transition to Other Land	NA	NA	NA
Other Land	Grassland	Grassland in transition to Other Land	Yes	Negligible	Yes
Other Land	Cropland	Cropland in transition to Other Land	Yes	Negligible	Yes
Other Land	Wetlands	Wetlands in transition to Other Land	NA	NA	NA
Other Land	Settlements	Settlements in transition to Other Land	NA	NA	NA

Yes: A numerical estimate of carbon change in the pool has been made.

No: No estimate of the carbon change in the pool has been made, but is likely to have occurred.

Negligible: Not significant under Tier 1 approach.

Not valid: Non-anthropogenic activity, or similar activity not to be considered in LULUCF sector.

NA: Not occurring. No estimate is made as it is assumed not to occur in an Irish context.

2 Land-Use Category 1: Forest Land

2.1 Data Sources for Forestry

Government policy is to increase the national forest cover from 7% to 17% of total land in the period 1990–2030. Since 1990 an estimated 233,000 ha of afforestation has occurred in Ireland, as shown in Fig. 2.1. The change in carbon stocks held within biomass and DOM for forestry has been estimated by COFORD (McGettigan *et al.*, 2006).

Three complementary data sources have been used to estimate the location and extent of existing and newly afforested areas in Ireland over the period 1990–2004, Coillte, the Forest Service and the Forest Inventory and Planning System (FIPS).

The Forest Service maintains two independent data sets. The first is a GIS database at land parcel resolution, and is derived from the larger Land Parcel Information System (LPIS), maintained by the Department of Agriculture and Food. The GIS database identifies the location and year of plantation of all new forestry obtaining grant aid.

The second database is a summary of afforested area based on the plantation areas declared in the official grant documentation. Penalties are applied if the area claimed by the landowner is misrepresented by more than 0.1 ha per application. This database is assumed to be the more reliable in terms of actual area of afforestation.

Figure 2.2 shows the history of afforestation in Ireland based on the official areas for the period 1970–2004. The key features are the significant growth in private afforestation, mirrored by a decline in state afforestation. There has also been a general increase in afforestation rates, particularly since 1985, when new strategic targets for national forest cover were implemented. Progress towards these targets has varied.

Table 2.1 shows an analysis based on the overlay of afforestation since 1990 and the GSM/IPCC soil association map for Ireland. A significant proportion of afforestation has occurred on organic soils, as identified by both CORINE and the GSM.

Table 2.1. Proportions of afforestation on mineral and organic soils, based on GIS analysis of 1990–2004 plantation and GSM and CORINE databases.

Data provider	Mineral soils	Organic soils
Coillte	0.56	0.44
Forest Service	0.70	0.30

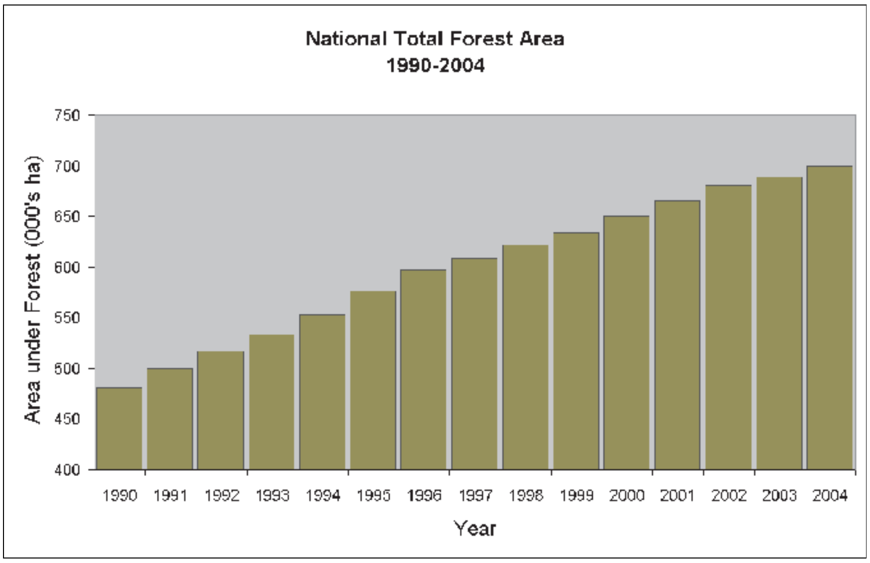


Figure 2.1. Afforestation in Ireland, 1990–2004 (Forest Service).

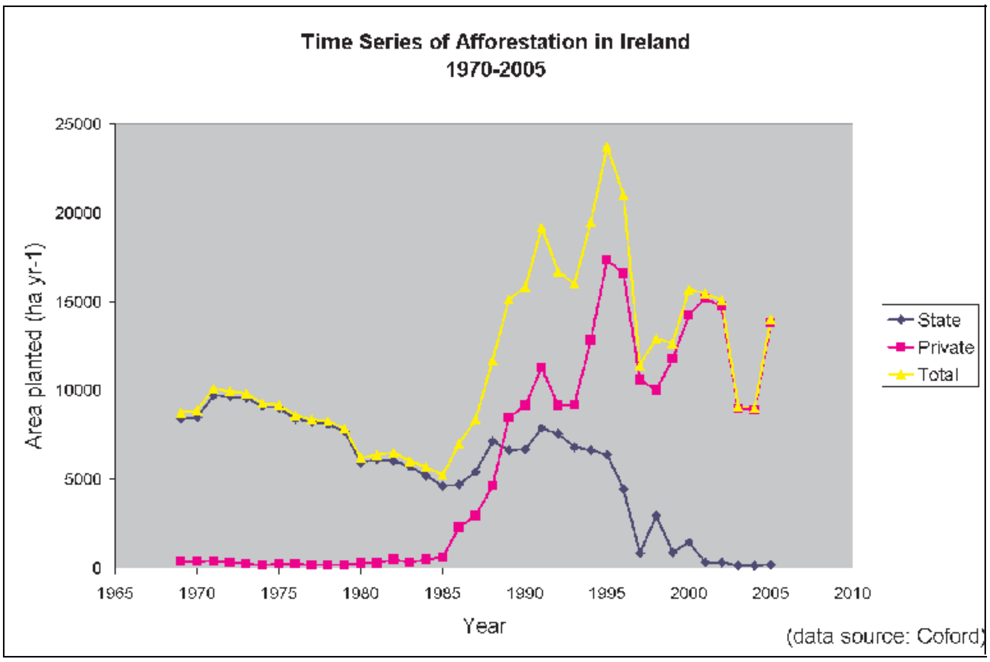


Figure 2.2. State and private afforestation in Ireland, 1970–2005 (COFORD).

A consequence of the afforestation policy and the grant aid scheme has been a decrease in the proportion of afforestation occurring on organic soils.

Figure 2.3 shows an example of the detailed information that can be inferred from the combined Coillte, Forest Service, CORINE and GSM soil databases.

The images show a west coast region. The data have been overlaid at the highest resolution, that of plantation land parcels. The databases can be used to estimate afforestation area, date of plantation, previous land use and soil type.

As with the CORINE determination of previous land use, the soil type determined from the GSM_IPCC look-up table can only be considered as indicative, and representing an averaged rather than a precise picture of the soil type in a given region. This may give rise to some anomalies. However, the proportion of afforestation seeming to occur on inappropriate soils from the spatial analysis is low (<1%).

The common reporting format (CRF) for LULUCF assumes the transition period is the same for all carbon pools, i.e. soil, living biomass and DOM. This is not the case in relation to afforestation on organic soils. The Tier 1 default transition period is 20 years. This is taken to be appropriate for forest living biomass and DOM. However, Hargreaves *et al.* (2003) showed that organic soils have a transition period of approximately 4 years under conditions typical in Ireland and Britain with a carbon loss from the soil at a rate of 4 t C/ha/year, compared to the IPCC default of 0.68 t C/ha/year over 20 years, i.e. a higher rate of loss over a much shorter period than the default values. The estimate of land area in transition to forestry on organic soils is therefore different from the area of forest biomass and DOM pools in transition.

Since 1990, 233,000 have been afforested, while the land parcel spatial analysis suggests a smaller area of 190,000 ha. Possible sources of the discrepancy are outlined in Appendix B. The COFORD biomass and DOM analysis is based on areas declared in the grant applications. To maintain consistency, these data are also used for area in the analysis of SOC changes.

CORINE 1990 is used as a first estimate of previous land use. However, it is possible for unrealistic previous land uses to emerge from the overlay of LPIS/Forest Service land parcels shapefiles onto the CORINE90 polygons.

Occasionally, CORINE has assigned a land-cover type in a given region that cannot be planted with trees, for example a waterbody or rocky outcrop. A pragmatic, *ad hoc*, solution to these inappropriate previous land-use types was to assume that, whilst the majority of land use in the polygon was indeed waterbody, the actual

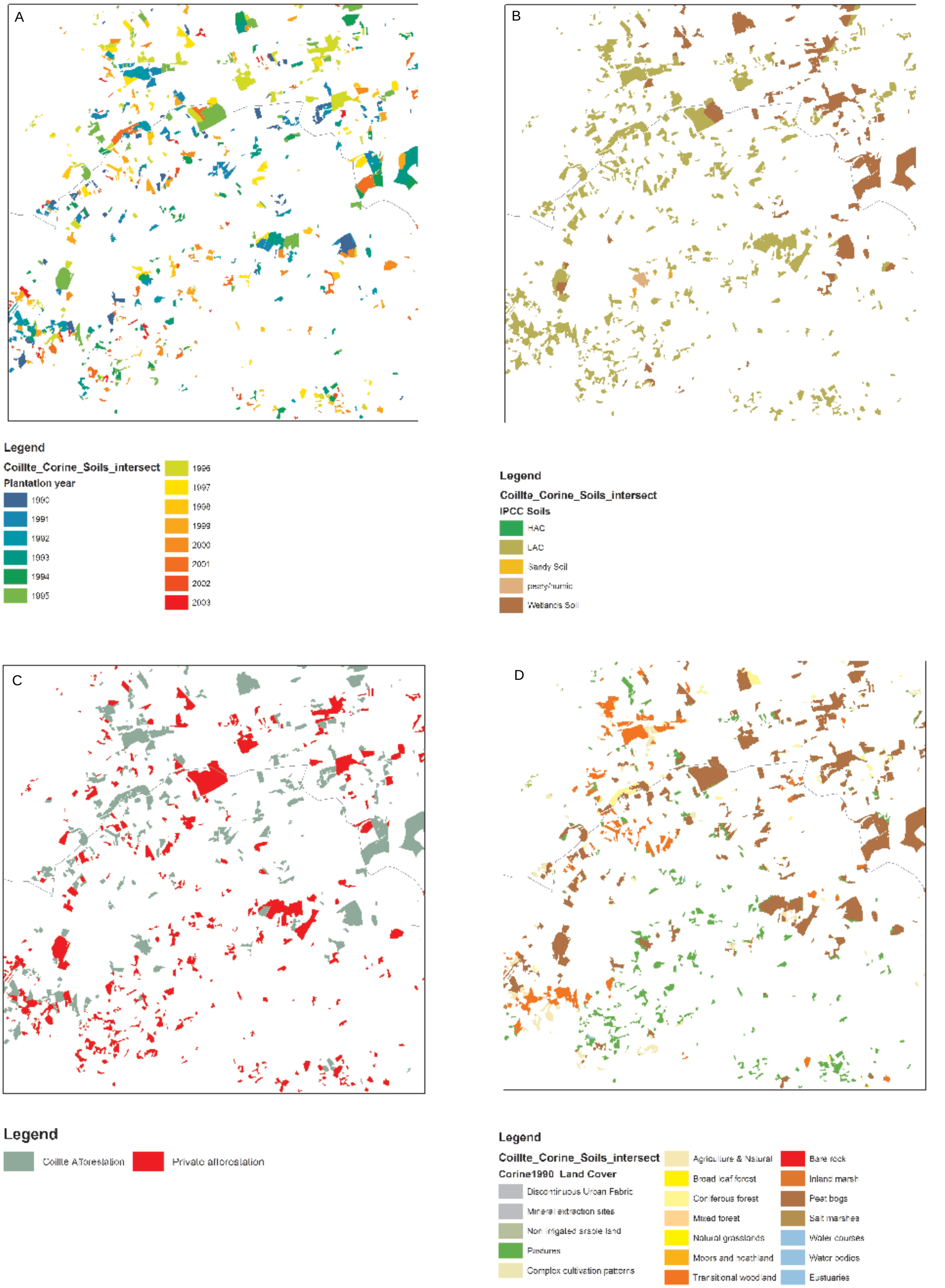


Figure 2.3. Maps showing afforested areas in a region near the west coast of Ireland. A) Year of plantation. B) Underlying soil type. C) Ownership (State or Private). D) Previous land cover (CORINE 1990).

Table 2.2. Proportions of mineral plantations IPCC soil type and CORINE activity based on the GIS analysis of the 1990–2004 plantation patterns for Forest Service data.

Previous land use	Proportion	IPCC	Δ SOC	IPCC
Highly improved grass	3.0×10^{-4}	1	–25.2	HAC
Unimproved	3.5×10^{-4}	1	0	HAC
Arable	0.038	2	12.0	LAC
Half pasture half arable	0.013	2	–5.29	LAC
Highly improved grass	0.4597	2	–22.6	LAC
Improved grassland	6.7×10^{-4}	2	18.1	LAC
Unimproved	0.3513	2	0	LAC
Arable	1.64×10^{-4}	3	16.2	Peaty/Humic
Half pasture half arable	3.19×10^{-4}	3	–4.42	Peaty/Humic
Highly improved grass	0.02072	3	–25.2	Peaty/Humic
Improved grassland	1.24×10^{-5}	3	–60.1	Peaty/Humic
Unimproved	0.1080	3	0	Peaty/Humic
Arable	8.75×10^{-5}	4	10.0	Sandy soils
Half pasture half arable	1.6×10^{-4}	4	–4.42	Sandy soils
Highly improved grass	1.02×10^{-3}	4	–18.8	Sandy soils
Improved grassland	3.17E–05	4	18.1	Sandy soils
Unimproved	6.208×10^{-3}	4	0	Sandy soils

afforestation took place on a smaller unimproved grassland area within the polygon. Table 2.2 shows the estimate of previous usage of mineral soils afforested since 1990.

A very high proportion of afforestation on mineral soils is found to have been grassland and on Low Activity Soil, summing to approximately 85% of the total afforestation on mineral soils, of which 46% is improved grassland and 35% is unimproved grassland.

2.2 Other Woodland Areas Footnote

A discussion of other woodland types, particularly hedgerows, is given in Appendix C.

2.3 Methodology for Forest Soils

The analysis of carbon release from forest soils is modelled on the default Tier 1 approach detailed in the IPCC GPG. Country-specific data are included in the estimates of carbon change due to the afforestation of organic soils; otherwise, the transition periods, emission factors and soil organic content of soils under various land-use types are the default values given in the appropriate tables in the IPCC GPG.

2.4 Organic Soils

Organic soils and mineral soils are treated differently using the IPCC methodologies. In this context, organic soils are areas of natural wetlands that have been drained for the purpose of human exploitation. The wetlands drained for forestry are derived from three distinct previous land-use categories:

1. Land previously drained and exploited for the extraction of peat. Forestry is an after-use activity for these lands. Historically, much of the cutaway peatlands, that is peatlands which had exhausted their energy potential but retained a significant depth of peat, were afforested. This practice has been heavily criticised by environmental groups, such as the Irish Peatland Conservation Council and Friends of the Irish Environment. These peatlands are treated as organic soils converted to forestry. The shift from State to private afforestation has led to a decline in the practice.

2. Wetlands previously drained for agriculture, principally improved pasture or rough grazing, but now converted to forestry. These lands are treated as grasslands on organic soils converted to forestry.

3. Natural wetlands drained and converted directly to forestry. These lands are derived from the 'Other Land' category.

With the exception of after-use afforestation figures for cutaway bogs from Bord na Móna, there are little *in situ* data on previous land use of afforested sites. It is assumed that organic soils converted to forestry derive from the three categories described above.

Once a wetland is drained, there is an acceleration of the decay process, leading to the release of the carbon stored in the organic matter in the form of CO_2. The net emission of carbon continues until there is an equilibrium between new carbon from biomass/DOM entering the soil and the decay of material already present. The land use has a significant impact on the rate and duration of the carbon release.

The estimated carbon emissions from afforestation on organic soils is given the following relationship:

$$\Delta C_{LF_{Organic}} = A_{Drained\ aff} \times EF_{Drainage} \qquad (2.1)$$

where $\Delta C_{LF_{Organic}}$ is the change in annual soil carbon stock for afforestation on organic soils, $A_{Drained\ aff}$ is the area of land drained for afforestation and $EF_{Drainage}$ is the carbon emission factor in units of tonnes C/hectare/year. The relationships hold for all drained wetlands organic soils, regardless of land-use activity.

As stated above, under Irish conditions, recent studies suggest an appropriate region-specific net emission factor of 4 t C/ha/year over a transition period of 4 years (Hargreaves *et al.*, 2003). The total emission is slightly greater than the default value, but spread over a much reduced time scale.

2.5 Mineral Soils

The behaviour of carbon within mineral soils due to land-use change depends on the previous land use, the new activity and climatic conditions. The change in carbon content in the soil is determined with reference to the default SOC_{Ref} under natural vegetation. One must estimate the SOC_{Before}, that is the SOC in the soil under the previous land use and land management regime, and then estimate the SOC_{After}, the SOC typical of lands after long-duration land use and land-use management under the new regime. It is assumed that the change in SOC occurs over a well-defined transition period (default 20 years). It is assumed that there is a linear incremental annual change in the SOC. The area of land in transition from one activity (grassland) to another (forestry) is estimated for each year. In reality, it is probable that the change in SOC following land-use change, or land management change, occurs asymptotically, with rapid change occurring in the years immediately following the conversion.

$$SOC_{Before} = SOC_{Ref} \times F_{LU} \times F_{MG} \times F_{I}$$

before change in land use (2.2)

$$SOC_{After} = SOC_{Ref} \times F_{LU} \times F_{MG} \times F_{I}$$

after change in land use (2.3)

Transition period 20 years

$$\Delta SOC = (SOC_{After} - SOC_{Before})/20 \qquad (2.4)$$

where ΔSOC is the annual rate of change in SOC.

After 20 years, the afforestation soil is no longer in transition and is classified as Forest remaining Forest. In the default Tier 1 approach, Forest remaining Forest on mineral soils is carbon neutral.

It is interesting to note that during the transition period, afforestation is a source of atmospheric CO_2, as SOC is lost from the soil, except for the case where previous land use was tillage. This default estimation has a significant impact on the net carbon sequestration due to forestry in Ireland as a large proportion of Irish forests are relatively young, and still in the transitional land-use phase.

Table 2.3 outlines the general trends in each of the carbon pools during the conversion from other land uses to forestry.

2.6 Results for Forestry

Figure 2.4 outlines the results of the analysis for total carbon stock changes in the forestry sector of LULUCF. Included in the diagram are the living biomass and DOM values as well as the soil component. Carbon loss from soils has a significant impact on the net sequestration of carbon within the forestry sector. This reflects the young age of a relatively large proportion of the Irish national forest. However, forestry, as a whole, is a net sink for atmospheric carbon. As the forest matures and the soil reaches an equilibrium carbon content, so the loss of carbon from the soils will diminish, and sequestration in the living biomass will become increasingly dominant.

The trends in carbon changes in afforested soils reflect the robust policy of afforestation in Ireland. The inter-annual variability in total area of afforestation, seen in Fig. 2.2, is smoothed somewhat by the 4- and 20-year transition period towards equilibrium assumed for organic and mineral soils, respectively.

Table 2.3. Trends in carbon stocks in carbon pool during transition.

		SOC (this study)	Biomass (COFORD)	DOM (COFORD)	Comment
Forest remaining Forest		No change	Increasing	Increasing	
Grassland converted to Forest	Unimproved grassland	Decrease	Initial decrease, followed by increase	Increasing	
Cropland to Forest		Increase			
Wetlands to Forest	Peatland to forestry	Decrease 4-year transition	Initial decrease, followed by increase	Increasing	Continued drainage of organic soils
Settlements to Forest Land	Not occurring				
Other Land to Forest Land	Unimproved grassland to forestry	Decrease	Initial decrease, followed by increase	Increasing	

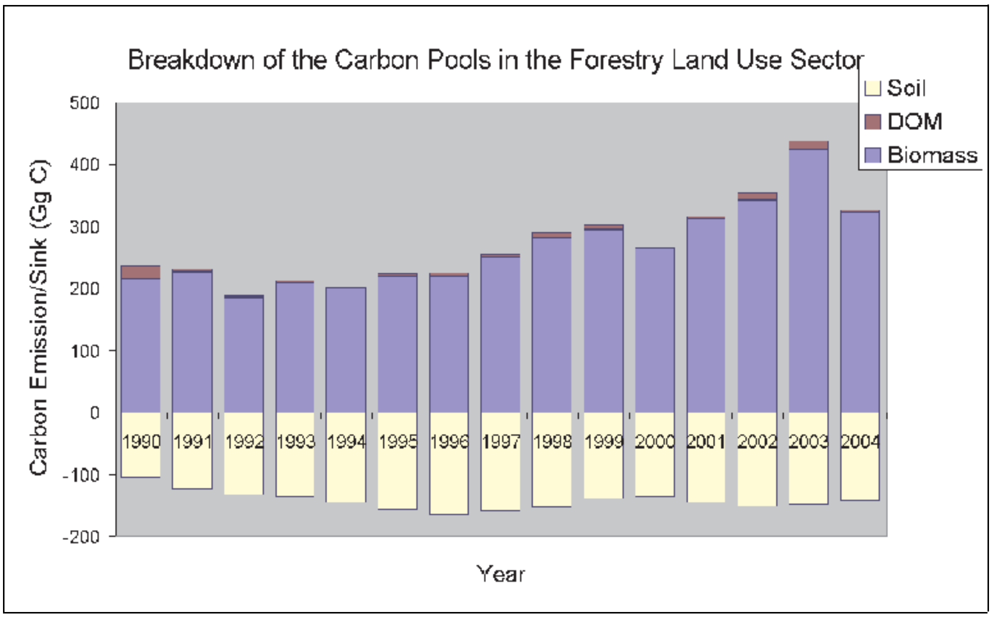


Figure 2.4. Change in carbon stocks in forestry carbon pools.

3 Grassland

Irish grasslands cover a total land area of 4.9 Mha, or *c.* 70% of the total land area, based on CORINE 1990 land-cover data.

3.1 Data Sources for Grassland

The majority of grasslands in Ireland are used for agricultural purposes: permanent pastures, hay and silage, or rough grazing. The principal source of data for annual area of grassland is the CSO. On average, the total area of agricultural grassland is *c.* 4.3 Mha. These grasslands can be divided into two management types: improved grasslands consisting of pasture, silage and hay; and unimproved grasslands reported as rough grazing by the CSO. Due to a change in CSO data collection and processing, 1991 is the first year of self-consistent CSO grassland data. An estimate has been made for improved grassland for 1989 and 1990. Figure 3.1 shows a breakdown of the time series of CSO agricultural grasslands from 1990 to 2004. The most obvious general trend is a shift from hay to silage production.

Not all grassland is used for agriculture; much of the remaining 0.6 Mha grassland areas are not exploited by anthropogenic activity, and might be termed 'natural grasslands'. As such, their potential for GHG emissions do not come under direct consideration under LULUCF. It is expedient in this analysis to include these unexploited grasslands in the 'Other Land' land-use category.

An analysis of the LPIS database from 2000 to 2006 indicates that of all land parcels reported as being in continuous agricultural usage, 84% were and remained grassland. However, even a small percentage change in the land use and management of grassland can represent a nationally significant change in the potential for GHG emission or sink.

There are important issues regarding the consistency of information within data from different sources. Internal consistency is of particular concern within the larger GIS databases. For example, the minimum land area unit within CORINE is 25 ha. The average land parcel/field size in Ireland is 3–5 ha. Also, farm holdings in Ireland are quite small, average farm size being of the order of 50–100 ha. The CORINE methodology tends to overestimate the spatial extent of the dominant land use in a given region. This is especially true where field sizes are small relative to the 25 ha minimum mapping area, in regions of mixed, heterogeneous, land usage. It is expected that any bias would 'average out', leading to reasonable estimates of total area under a given land class. However, in regions where one particular land cover is especially dominant, as

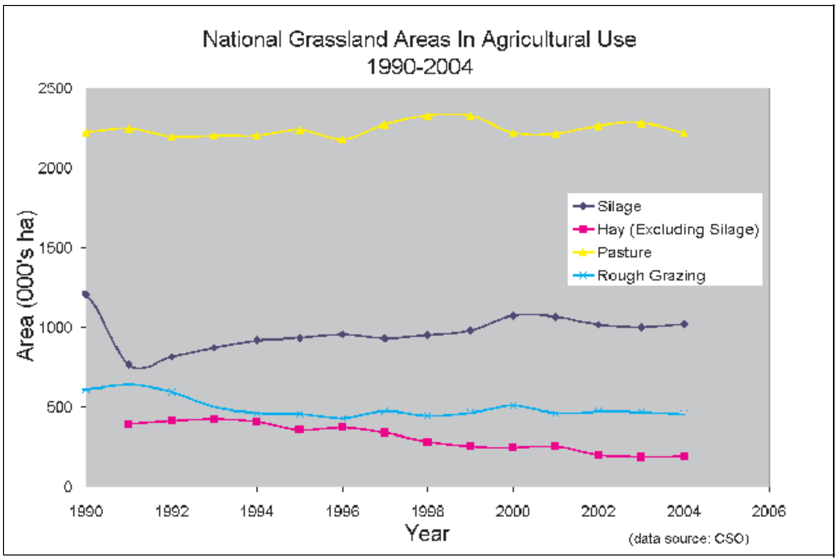


Figure 3.1. Agricultural grassland types in Ireland, 1990–2004, CSO.

is the case with grassland in most of Ireland, then smaller patches of other land use are subsumed into the CORINE grassland class.

In brief, other land-use activities occur in smaller and fragmented plots within the larger grassland landscape. Figure 3.2 illustrates this point using the CORINE 2000 land cover, and the higher resolution LPIS 2004 farming activity data for the same part of the country. The CORINE data suggest a more uniform land cover than is the reported case seen in the LPIS data. Appendix B illustrates the same point in the context of forestry.

3.2 Methodology for Grasslands

Estimates have been made for the two carbon pools, living biomass and soils, and for CO_2 emissions due to the spreading of lime on agricultural soils.

3.2.1 Lime spreading

Liming is included, somewhat anomalously, within the LULUCF section of emissions reporting. Arguably, the practice of spreading lime to control soil pH is an agricultural management practice similar to the application of nitrogen fertiliser, and should be included in the agriculture sector. As it stands, the liming of soil is a key source within the LULUCF sector for Ireland.

CO_2 emissions from lime, in a given year, are estimated as a fixed proportion of the lime sales. The lime sales figures are supplied by the Irish Fertilisers Association, through IBEC. The emission factor is the same regardless of activity; therefore no attempt has been made to divide the CO_2 emission from liming between land-use classes. Since, in reality, the vast majority is spread on grassland, the entire activity has been included under the grassland sector. Figure 3.3 shows the time series for lime sold for spreading in Ireland since 1988.

Equation 3.1 shows the expression used to estimate carbon emissions due to lime spreading on agricultural lands. The sales data used to estimate the quantity of lime spread in Ireland do not differentiate between lime sources. However, the majority of producers of liming agents in Ireland manufacture crushed limestone based products.

$$\Delta C_{GG_{Liming}} = M_{Limestone} \times EF_{Limestone} + M_{Dolomite} \times EF_{Dolomite} \quad (3.1)$$

where M is the quantity in tonnes of liming agent spread on the land in a given year and EF is the emission factor.

Figure 3.4 shows the times series of CO_2 emissions to the atmosphere based on the default EF of 0.12 t carbon (CO_2) per t lime sold for spreading. In deriving the emission factor of 0.12 t C per t lime spread as $CaCO_3$, the IPCC GPG assumes that all carbon in lime is lost to the atmosphere as CO_2 during the year of spreading. The carbon atom in the $CaCO_3$ molecule is 0.12 of the total molecular mass.

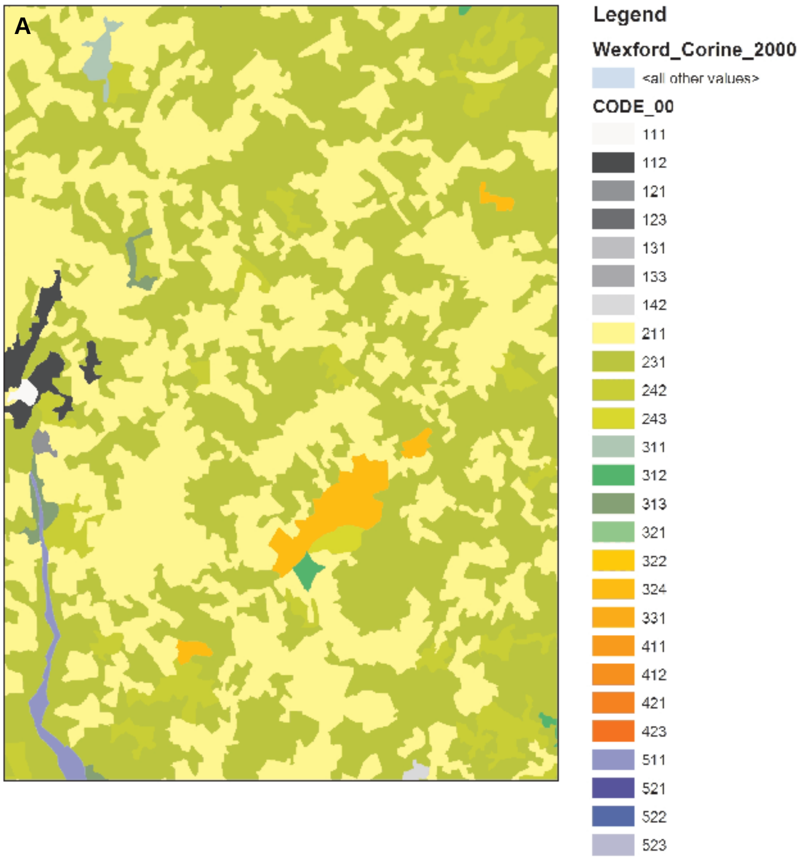
The release of CO_2 from liming material is a complex process. Liming of soil is important to maintain optimum agricultural productivity. Low pH soils tend to low productivity, which translates to low plant uptake of nitrogen fertilisers, the knock-on effect of which is higher N_2O emissions to the atmosphere. Some research is needed on the whole system response to liming, and to determine whether the CO_2 emissions from liming are offset by reduced emission of N_2O, or improved carbon uptake by living biomass or soil.

A Teagasc survey of the pH condition of Irish soils, based on soil samples submitted to regional laboratories for nutrient analysis, suggests that, nationally, soil pH is less than optimum, and liming should be undertaken on a majority of Irish soils to improve plant productivity.

Cuttle and James (1995) showed that a significant proportion of carbon in lime, spread on upland grasslands in Wales, was lost from the soil through leaching, 24% over 4 years. Further analysis of this and similar studies needs to be undertaken in order to interpret the results in an Irish context and improve emission estimates.

3.3 Grassland Soil and Biomass Carbon Stock Change

Figure 3.5 shows time series of the total improved grassland area in Ireland since 1989. Figure 3.6 shows the changes in unimproved grasslands over the same period. The minimum area of land under improved grassland was approximately 3.4 Mha in 1989, immediately prior to the UNFCCC reporting period. An uneven expansion in improved grasslands area occurred during the 1990s, reaching a maximum of 3.55 Mha in 1998. Thereafter, there has been a steady decline in improved grasslands reported by the CSO. In 2004 the area is similar to that at the beginning of the reporting period.



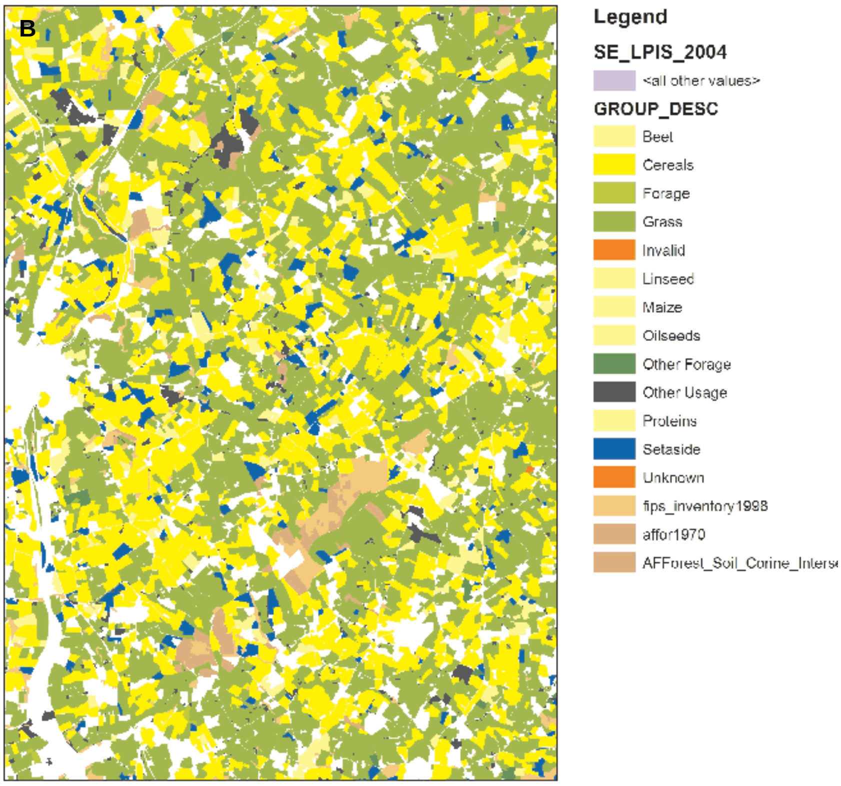


Figure 3.2. A) CORINE 2000 land-cover class. B) Land Parcel Information System land use showing fragmentation of land-use activities.

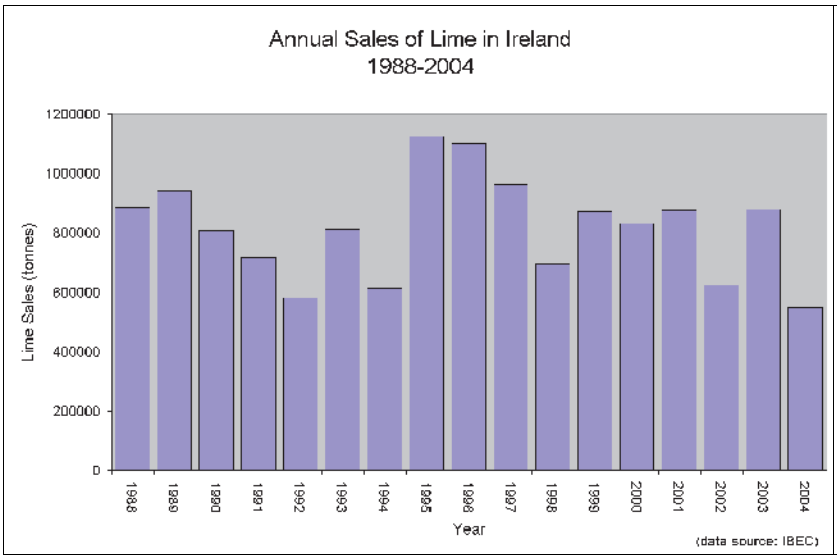


Figure 3.3. Lime sales in Ireland, 1988–2004. Data source IBEC.

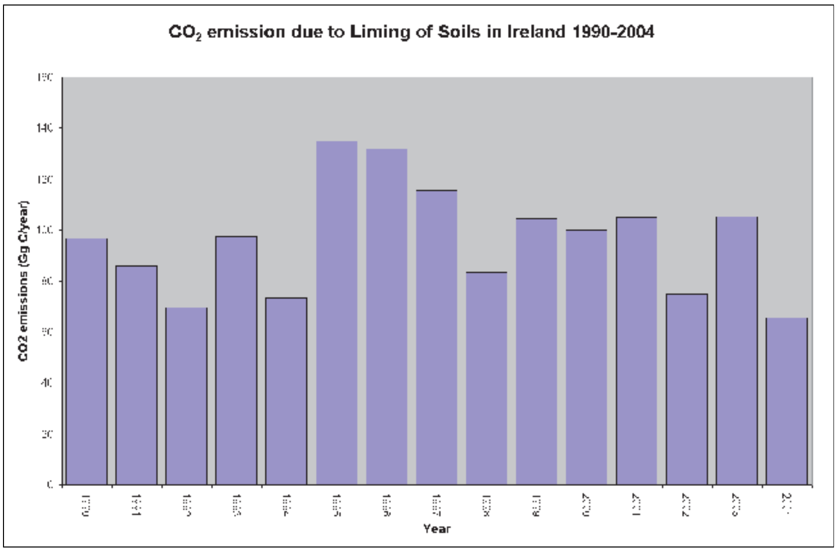


Figure 3.4. Estimated carbon dioxide emissions from lime spreading on Irish soils.

Agricultural use of unimproved grassland areas decreased rapidly in the first half of the 1990s, and has remained effectively constant since 1994.

In order to assign appropriate land-use change to these grassland figures, one must make certain assumptions about the behaviour of farmers. When the exploited grassland area increases (in a given year) the previous land use must be estimated. Similarly, when the grassland area decreases, an estimate must be made of the likely new land use. These estimates cannot be made in isolation from what is known about the demands for land from the other land-use sectors. For example, settlements demand land, since 80% of the land suitable for construction is grassland, then it is reasonable to assume that 80% of the land used for settlement was previously grassland.

The area of land remaining grassland and the area of land in transition to grassland are complex functions of the net demands and supply of land from other uses. The overriding requirements are:

- The total area of land in agriculture in a given year is consistent with the CSO figure

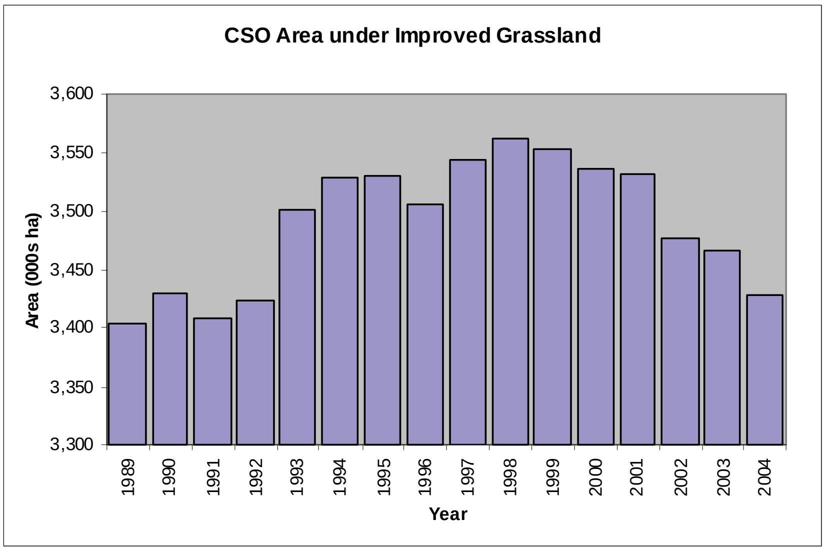


Figure 3.5. Time series of improved grassland in agricultural usage.

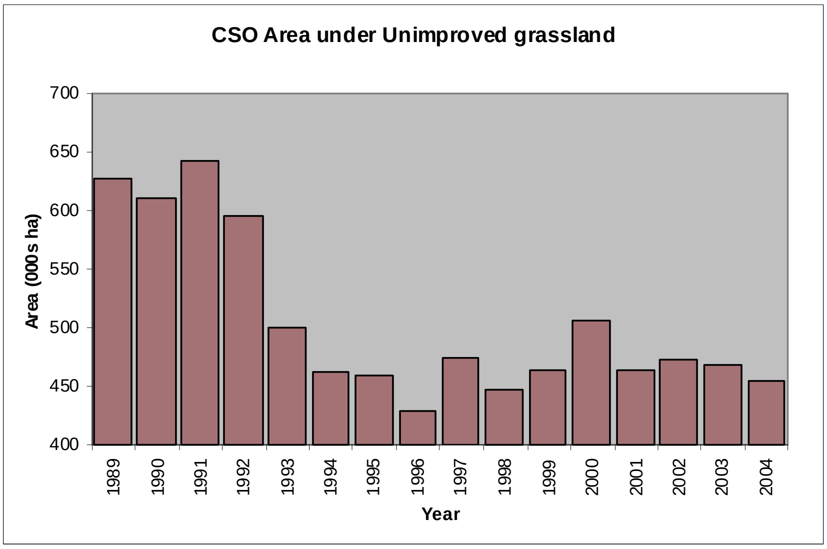


Figure 3.6. Time series of unimproved grasslands in agricultural usage.

- The demands for land to other land uses are met
- The transfer of land from other land uses is accommodated
- The total land area in Ireland remains constant and is consistent with the CORINE 1990 value.

The following assumptions have been made regarding farming behaviour:

- An increase in improved grassland is derived from unimproved grassland. That is to say, the farmer makes the decision to improve grasslands previously exploited as rough grazing. The time series in Figs 3.5 and 3.6 show this to be a reasonable assumption in the early 1990s, when there was a strong correlation between the increase in improved grasslands and a decrease in reported rough grazing. Since 2001, the decrease in improved grassland was not being matched by an increase in rough grazing. This implies a net conversion of grasslands to land uses, principally to Other Land, but also to forestry, croplands and settlements.

- An increase in unimproved grassland is derived from the natural grassland, that is, from the Other Land category. Therefore there is a transfer of area from the Other Land category to grassland; however, the change in land use is modelled as a conversion from unexploited natural grassland to rough grazing of unimproved grassland.

- Where there is a demand for grassland to be converted to forestry, it is assumed to be unimproved grassland, as it is unlikely that a farmer would abandon the higher economic returns possible from improved pastures. Forestry is a 'last resort' activity as it fixes the land use for a long period.

- A demand for transfer of grassland to cropland is assumed to be a transfer from improved grassland. Crops require good quality, well-managed land; it is unlikely that unimproved grasslands would meet the requirements of conventional crops. In the future, certain energy crops, such as *Miscanthus*, may indeed be planted on unimproved grasslands or on croplands where traditional crops are no longer economic.

- When there is a demand for grassland to convert to settlements, the required area is divided between grassland types in proportion to their national coverage. The land is acquired regardless of previous use.

- Previously exploited cutaway peatland converted to grassland is assumed to be improved grassland. This area is reported to the EPA by Bord na Móna. The total improved grassland is adjusted accordingly; however, the area of peatland converted to grassland is very small.

3.4 Improved Grassland

Improved grasslands are well managed, receiving artificial fertiliser and other treatments such as liming and re-seeding to optimise grass productivity. It has been shown that these improved grasslands achieve a higher SOC concentration than that typical of natural vegetation (Brady and Weil, 2002). This is reflected in a default F_{MG} factor of 1.14, with F_I equal to 1.11, to reflect the additional input. The land-use factor, F_{LU}, equals 1.00 for grassland (see Table 3.1).

Grazed unimproved grassland does not achieve SOC concentrations greater than those typical of natural vegetation and may, in fact, degrade due to the animal disturbance of the soil, particularly peaty soils. This is reflected in an F_{MG} factor of 0.95 (see Table 3.2).

The grasslands need to be further subdivided into grassland areas remaining as grasslands, and those areas in transition to grassland from another land use or land management type, based on the available CSO data.

3.4.1 Improved grassland remaining improved grassland

These grasslands have experienced essentially the same management activity on an ongoing basis over many years. Assuming a default transition period of 20 years, the maximum area of improved grassland whose management has not changed is equal to the minimum area of improved grassland during the previous 20 years. As stated previously, there is no consistent CSO estimate of grasslands prior to 1991, because of a change in survey methodology. An estimate has been made of the 1989 and 1990 grassland areas based on a linear extrapolation of trends in land usage in the years before and after 1991.

From Fig. 3.5 it can be seen that the 1989 area of improved grassland is the minimum area estimated over the 15-year period from 1989 to 2004. Therefore, the estimate for improved grassland remaining grassland has remained constant over the inventory period.

3.4.2 Lands in transition to improved grassland

In a given year, the estimate of lands in transition to improved grassland is equal to the difference between the CSO value for improved pasture and the land remaining improved pasture that year, i.e. the 1989 area.

$$\text{Grassland}_{\text{Imp}_{\text{Transition}}} = \text{CSO}_{\text{Imp}} - \text{Grassland}_{\text{Imp}_{\text{Remaining}}} \quad (3.2)$$

This assumes particular farmer behaviour. The farmer's use of improved grassland is a response to the changing potential for good economic returns from grassland agriculture. In response to improved potential for profit, during the first half of the 1990s, farms converted significant areas of unimproved grasslands to improved grasslands. Much of this land derived from unimproved grassland already employed by farmers as rough grazing. Where necessary farmers also converted unimproved

Table 3.1. Example of estimation of the annual change in soil organic carbon (ΔSOC).

Cold temperate moist				Transition period 20 years	
Unimproved grassland (t C/ha for 0–30 cm depth)					
	SOC_{Ref}	F_{LU}	F_{MG}	F_I	SOC_{Before}
HAC	95	1.00	1.00	1.00	95.00
LAC	85	1.00	1.00	1.00	85.00
Peaty/Humic	115	1.00	1.00	1.00	115.00
Sandy	71	1.00	1.00	1.00	71.00
Improved grassland					
	SOC_{Ref}	F_{LU}	F_{MG}	F_I	SOC_{After}
HAC	95	1.00	1.14	1.11	120.21
LAC	85	1.00	1.14	1.11	107.56
Peaty/Humic	115	1.00	1.14	1.11	145.52
Sandy	71	1.00	1.14	1.11	89.84
					t C/year
			ΔSOC	HAC	1.26
				LAC	1.13
				Peaty/Humic	1.53
				Sandy	0.94

Table 3.2. Example of estimation of the annual change in soil organic carbon (ΔSOC).

Cold temperate moist				Transition period 20 years	
Ungrazed unimproved grassland (t C/ha for 0–30 cm depth)					
	SOC_{Ref}	F_{LU}	F_{MG}	F_I	SOC_{Before}
HAC	95	1.00	1.00	1.00	95.00
LAC	85	1.00	1.00	1.00	85.00
Peaty/Humic	115	1.00	1.00	1.00	115.00
Sandy	71	1.00	1.00	1.00	71.00
Degraded, grazed unimproved grassland					
	SOC_{ref}	F_{LU}	F_{MG}	F_I	SOC_{After}
HAC	95	1.00	0.95	1.00	90.25
LAC	85	1.00	0.95	1.00	80.75
Peaty/Humic	115	1.00	0.95	1.00	109.25
Sandy	71	1.00	0.95	1.00	67.45
					t C/year
			ΔSOC	HAC	–0.24
				LAC	–0.21
				Peaty/Humic	–0.29
				Sandy	–0.18

grasslands not previously used as rough grazing, and here defined as Other Land.

Since 1998, the potential returns from these sectors have decreased, for various reasons. In response, farmers have discontinued the active management of these lands. Also the farmers appear not to be using these lands as rough grazing, as the CSO rough grazing figures are static or in decline during the same period. Therefore, the grassland reverts to the status of unimproved grassland, not exploited within agricultural use, and therefore Other Land. This is clearly implied in the time series of total CSO grassland in agricultural usage, which has seen a 60,000 ha decline since 2000. Figure 3.7 illustrates these trends.

During the reporting period there has been a steady increase in croplands, as will be examined in the next chapter. This is not on the same scale as changes in improved grassland. It is assumed that the demand for cropland will have prompted the conversion of improved grassland to cropland during this period. Conversely, there are occasions when there is a decrease in croplands from one year to the next; it is assumed that these lands are not abandoned but are seeded to improved grassland. Figure 3.8 shows the occasions when croplands are converted back to improved grasslands.

Figure 3.9 shows the time series for unimproved grassland since 1989. During the early 1990s there was a gradual decline in the agricultural use of unimproved pasture, i.e. rough grazing. This may reflect a decline in the practice of grazing sheep on mountains and other

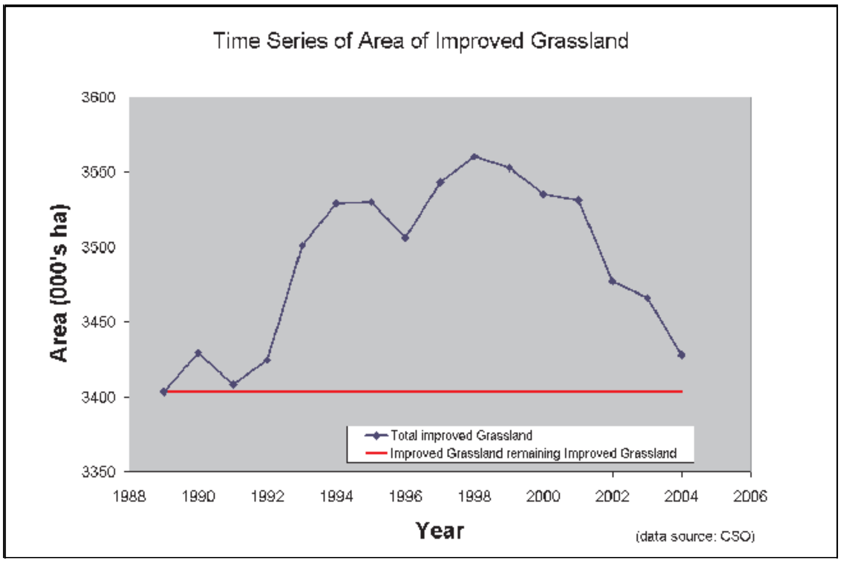


Figure 3.7. Area of improved grasslands and grasslands remaining grasslands, 1990–2004.

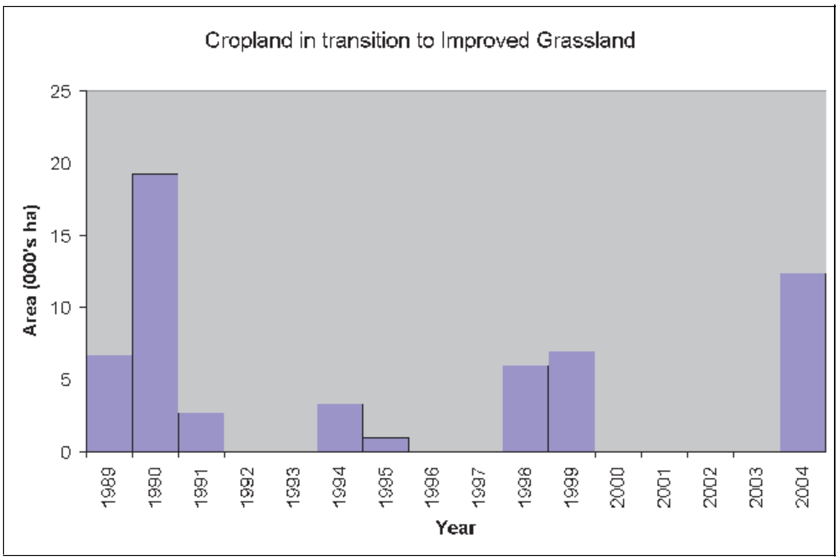


Figure 3.8. Area of croplands in transition to improved grassland, 1989–2004.

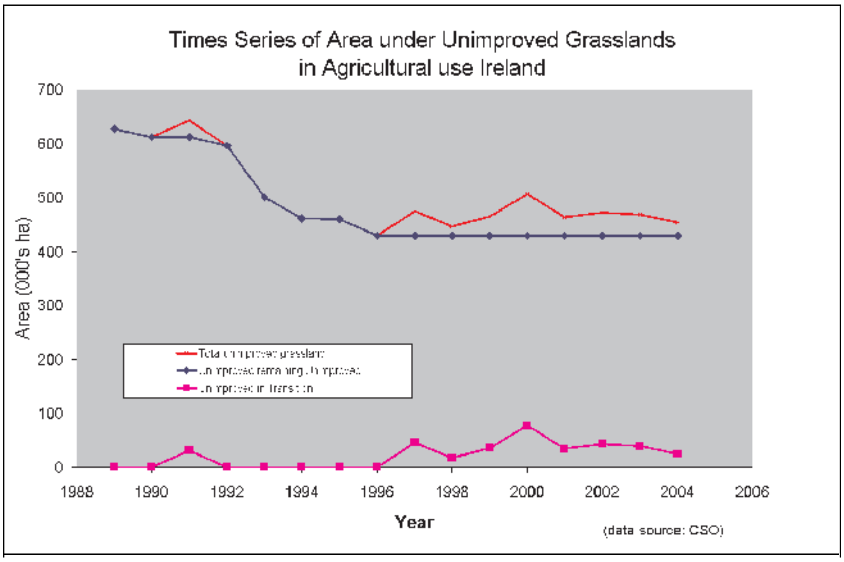


Figure 3.9. Unimproved grasslands remaining and in transition: 1990–2004.

poor-quality lands, and an intensification of farming leading to a conversion of rough grazing towards higher quality and better managed grasslands.

The decline in the use of unimproved grassland is quite marked, so much so that it outpaces the increased use of improved pasture in the early 1990s, and one sees an overall decrease in agricultural grassland.

The coincident increase in improved grassland during the early 1990s' decline in rough grazing is considered to reflect the practice of farmers improving their grazed unimproved grasslands. Apart from minor inter-annual variations, the area of agricultural unimproved grasslands has remained constant since 1994. There is no evidence that the decline in improved pasture has seen these lands return to rough grazing. Therefore these lands have largely been abandoned (Other Land category) or been converted to another land use (settlement, forestry, croplands, etc.).

As mentioned in Chapter 2, there is a demand from afforestation for both improved and unimproved grasslands. These areas are implicit in the CSO data. When the total improved grassland area increases, this is in spite of the area of grassland converted to forestry. A simple 'double-entry bookkeeping' approach is employed to include grassland transition to forestry in the inventory, and the total grassland area remains consistent with the CSO figures. A similar methodology is used when afforestation demands conversion from rough grazing and the Other Land class.

There is some concern that re-seeding of permanent grassland represents a significant disturbance of the soil, and may offset the carbon sequestration which ordinarily occurs during the transition period from unimproved to improved grassland.

The minor components driving changes in grassland area are lands required for settlements and those peatlands converted to grassland. The absolute areas involved are relatively very small and need not be discussed in the context of the overall grassland carbon stock change Table 3.3 summarises the impact of changes in farm practices and land-use change on SOC with regard to grasslands.

3.5 Lands Converted to Grassland – Change in Living Biomass Carbon

The expressions used to estimate change in carbon stocks in living biomass during conversion to grassland in Eqn 3.3. Table 3.4 shows the corrected IPCC default dry matter (DM) content of living biomass per hectare in grassland. Assuming 0.5 t C/t DM carbon content yields an estimate of 6.0 t C/ha. This value is taken to be equal to the change in carbon due to 1 year's growth, ΔC_{Growth}. It is assumed that only croplands and exploited peatlands have been converted to grassland. There is no biomass present on exploited peatland. During conversion all living biomass is removed from cropland. The default living biomass carbon content on croplands is 5.0 t C/ha. Its is assumed that there is zero biomass extant on exposed peatland. Therefore, in both cases, the net impact of

Table 3.3. Tendency in soil organic carbon following change in management of or conversion to grassland

		SOC	Comment
Grassland remaining Grassland	Improved grassland remaining improved grassland	No change	
Grassland remaining Grassland	Unimproved grassland remaining unimproved grassland	No change	
Grassland remaining Grassland	Unimproved grassland converted to improved grassland	Net increase	
Grassland remaining Grassland	Improved grassland converted to unimproved grassland	Net decrease	
Other Land convert to Grassland	Unimproved grassland converted to unimproved grassland	No change	Previous unexploited land converted to rough grazing
Wetlands converted to Grassland	Peatland converted to improved grassland	Net decrease	Continued drainage of organic soil
Cropland to Grassland	Cropland to improved grassland	Net increase	

Table 3.4. IPCC default biomass carbon stocks present on land converted to grassland (corrected extract from IPCC GPG Table 3.4.9).

IPCC climate zone	Total (above and below ground) non-woody biomass (t DM/ha)	Error
Cold Temperate Wet	12.0[1]	75%

[1]Living biomass is incorrectly reported as 13.6 t DM/ha in IPCC GPG (1996).

conversion to grassland is an increase in stocks of carbon in living biomass.

$$\Delta C_{LG_{LB}} = A_{Conversion} \times (L_{Conversion} + \Delta C_{Growth}) \quad (3.3)$$

where $L_{Conversion} = C_{After} - C_{Before}$.

3.6 Results for Grasslands

The results of the LULUCF analysis for grassland are shown in Fig. 3.10. Lime spreading is clearly the dominant source of carbon emissions to the atmosphere. The variability is due to differences in sales of lime. Emissions from grassland soils are more variable. Soils show the potential to be either a source or a sink for atmospheric carbon. The variability reflects the dynamic shift of relatively large areas of land between improved and unimproved land-use categories, as well as conversion of modest areas being converted from cropland and peatlands.

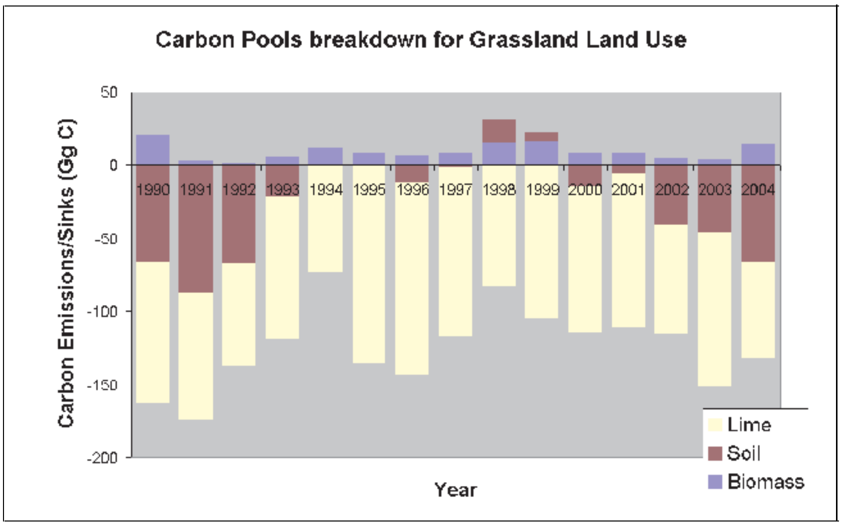


Figure 3.10. Change in carbon stock within the grassland land-use sector.

4 Cropland

Cropland area is approximately 10% of the agricultural land in Ireland, and is a relatively minor source of LULUCF GHG activity. It is not a key source in the LULUCF sector. The censuses of agriculture data compiled in 1970, 1980 and 1990 show a steady decline in cropland over these two decades, and a continuation of the decline in Irish agriculture since the 1950s.

4.1 Data Sources for Croplands

Total annual cropland areas are derived from CSO annual crop statistics. Figure 4.1 shows the time series of cropland area since 1990. The trend in the CSO figures has been for an increase in area under cropland since the early 1990s, with occasional setbacks. Much of the growth has been in fodder crops such as maize.

CSO data collection methods adopted in 1991 are not completely compatible with data from before 1991. This makes it difficult to construct a completely consistent time series from 1970 to 2004 for the purposes of estimating cropland in transition over the default 20-year transition period.

The gradual increase in cropland area since 1990 has led to a gradual increase in the annual carbon loss from these lands. However, the total area under croplands is still well below the value reported in the 1970 census. Therefore the assumption has been made that there were no lands in transition to croplands at the start of the reporting period. That is to say, it has been assumed that no land moved into tillage during the period 1970–1990.

Set-aside is a feature of the Arable Crops Aid scheme and is a payment system by which lands are removed temporarily from tillage, and any other human or animal food production activity, with the exception of limited grazing or silage and hay harvesting at the end of the growing season. The scheme is an EU initiative to discourage overproduction of crops and to help protect European soils from over-exploitation. The scheme began in 1993. Tillage farmers operating under the Arable Crops Aid system are obliged to set aside a minimum proportion of their land to non-food activity, usually green cover. However, an individual farmer may decide to put a larger proportion of the farm into set-aside, up to a maximum limit. A detailed official record is kept of set-aside lands, as the farmer receives payment at a per hectare rate. Also, activity on the claimed set-aside is audited to ensure compliance with the terms of the scheme. The CSO

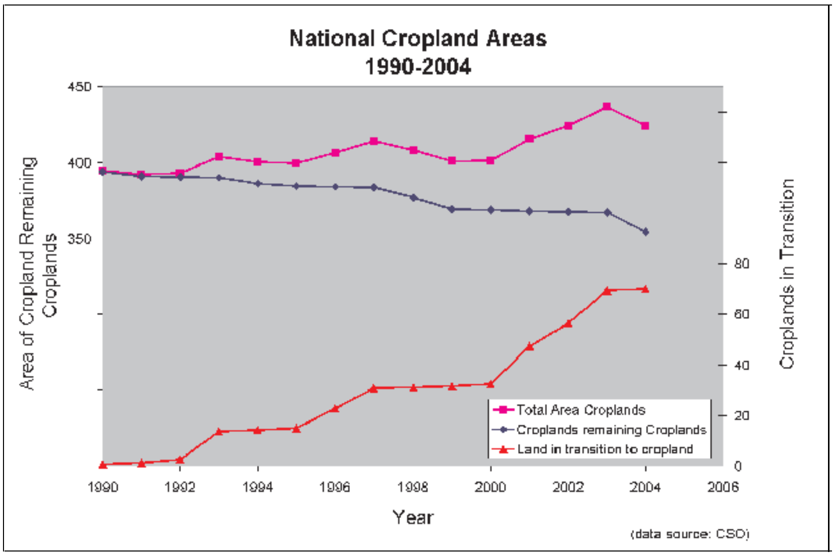


Figure 4.1. Time series of croplands in Ireland, 1990–2004: total area, area of cropland remaining cropland, and cropland in transition (note different scales).

reports annual set-aside area under its 'Other Crops' heading.

Under IPCC GPG, set-aside lands are to be treated as cropland, regardless of the temporary land use.

Figure 4.2 shows the CSO statistics for 'Other Crops' which includes set-aside. The average 'Other Crops' class within the CSO database from 1988 to 1992 was 5.6 kha, including maize. With the commencement of the set-aside scheme the 'Other Crops' increased dramatically. Maize was reclassified under its own crop description in 2000. Assuming non-set-aside other crops have remained constant, using 'Other Crops' as an estimate of set-aside overestimates the area by between 15% and 33%.

The 'Other Crops' CSO figures are therefore a conservative overestimate of lands in set-aside. However, it is clear from the trend in 'Other Crops' that set-aside is indeed the main component.

A number of land management strategies qualify as set-aside:

- Natural regeneration of green cover
- Planting a mixture of grasses, mustard paella
- Planting fodder rape
- A range of non-food-related activities such as short rotation forestry.

Therefore, set-aside may go to forestry rather than grassland. These set-aside forest areas may not appear in the Forest Service database, as they are not necessarily grant-aided under a Forest Service scheme. The LPIS data contain some insight into set-aside forestry. According to the analysis, in 2005 96% of set-aside was reported as 'green cover' or simply 'set-aside'. The use of set-aside for non-food crops appears to be increasing steadily. However, the reported use of set-aside for forestry is still low, at just 0.6% of total set-aside in 2005.

The LPIS is a spatially referenced database that documents those agricultural activities that receive state or EU support payments. Annually, the coverage of the LPIS varies, as necessary, to include all land parcels claimed for under appropriate schemes administrated by the Department of Agriculture and Forestry (DOAF).

The LPIS has potential as a land-use tracking system in the coming years, as the system develops and grows. However, in this analysis the LPIS was used only to estimate the soil types typical for crops in Ireland. There are few crops that do not benefit from direct support/subsidy and, as of 1999, it is obligatory that a land parcel claiming under the Arable Crop Aid scheme has an LPIS number. Therefore the LPIS can be considered a comprehensive database of croplands.

The main disadvantage of the LPIS, with regard to LULUCF, is that it is not a complete time series back to

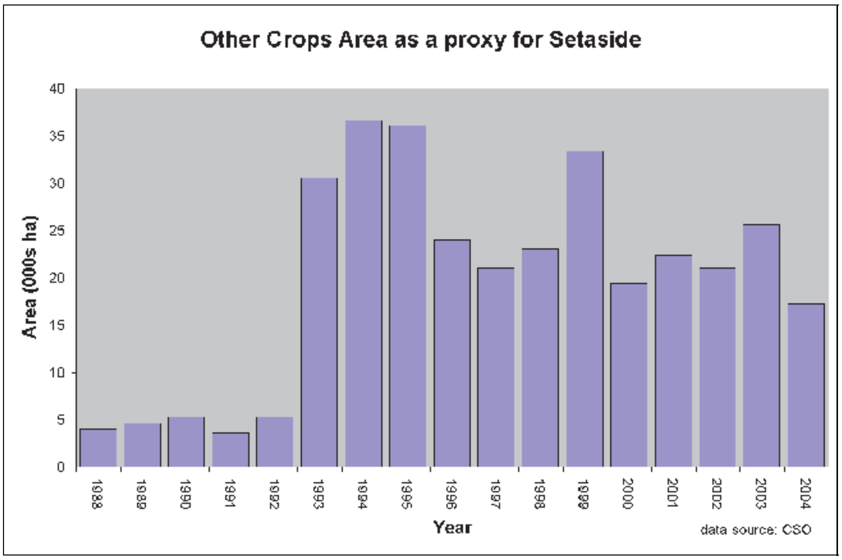


Figure 4.2. Time series of area of set-aside in Ireland, 1988–2004.

1990, and does not have complete coverage under all land-use classes.

Figure 4.3 shows a detailed region of the results of a GIS analysis of an overlay of an LPIS cropland shapefile over the IPCC soil classes map. The GIS analysis for the whole country suggests that very limited planting of crops occurs on organic soils. A small proportion of planting occurs on High Activity Clay (HAC) soils and sandy soils; the majority soil type under crops is Low Activity Clay (LAC).

Figure 4.4 shows the CSO cropland area and the LPIS GIS area from the years 2000–2004. There is good agreement, but with evidence of a systematic difference of the order of 10%, perhaps due to differences of definition of what constitutes croplands. There is a marked difference between the two data sets in 2004; however, there was a change in the data format of the LPIS data for that year, and so this may be an artefact of conversion between formats.

4.2 Methodology for Croplands

The planting of crops disturbs the soil, and a greater depth of soil carbon becomes vulnerable to decay, leading to the release of CO_2. In Ireland, conversion from any other land-use activity to cropland leads to carbon release from the soil.

The majority previous land use is grassland on LACs and HAC soils, 98%, and just 2% on organic soils. With negligible additional uncertainty in total carbon exchange to the atmosphere, it can be assumed that the previous land use is exclusively improved grassland. During conversion, there is also significant loss of carbon from biomass in the first year as the grassland is ploughed up in preparation for planting.

In order to estimate land in transition into and out of croplands, it is necessary to assume certain behaviour patterns in farmers. Firstly, it is assumed that farmers adopt a conservative attitude and are inclined to persist in their decisions after a change of land use. Therefore, farmers who left tillage in the 1970s and 1980s did not return within a 20-year period. That is to say, the croplands converted to other use, assumed grassland, were allowed sufficient time to complete the transition to the new land use. Therefore, it is assumed that all lands converted to croplands during the reporting period 1990–2004 were previously long-established improved grasslands. This assumption implies a relatively high initial SOC in the soils.

The minimum cropland area in the period 1990–2004 was reported in 1990. To remain consistent with the assumption of conservative farmer behaviour, any conversion of croplands to other use during the reporting period represents a reduction in the area of Cropland remaining Cropland. Cropland remaining Cropland, in the Tier 1 method is carbon neutral.

Lands converted to croplands since 1990 are 'in transition', and will remain croplands for at least the default transition period of 20 years since conversion.

An analysis of the LPIS data over the 6-year period 2000–2005 shows farmer behaviour to be more complex, with frequent switching between crops and grass, probably in the context of a regular crop rotation scheme. Under the IPCC GPG, short-term use of croplands for grass does not represent a change of land use, as the land is destined to be used for crops again in the near future. However, these grasslands, used for agricultural purposes, are included in the CSO statistics within improved grasslands. Therefore there is a possible underestimate of 'Cropland remaining Cropland". However, the uncertainty in the estimation of total LULUCF carbon release is not affected. Regardless of whether the strict definition of the land use should be Cropland or Grassland, the reality is that these areas are treated correctly as a transition of tilled soil to grass.

An inconsistency arises when these misrepresented temporary grasslands return to crop production. All grasslands converted to cropland are assumed to have been in a stable high SOC improved grassland condition. However, the temporary grasslands are, in fact, somewhat degraded by previous cropland usage. This leads to an overestimate of CO_2 emissions. At present there are not sufficient data available to resolve this problem, and the method adopted is consistent with the IPCC GPG advice that in cases of uncertainty a conservative overestimate of emissions should be made. (Note that these temporary grasslands are not included in the official set-aside figures, which appear in the CSO type of cropland.)

The IPCC GPG method of estimating carbon emissions from Cropland remaining Cropland is given in Eqn 4.1. However, in the Tier 1 approach it is assumed that there are no changes in carbon stocks for Cropland remaining

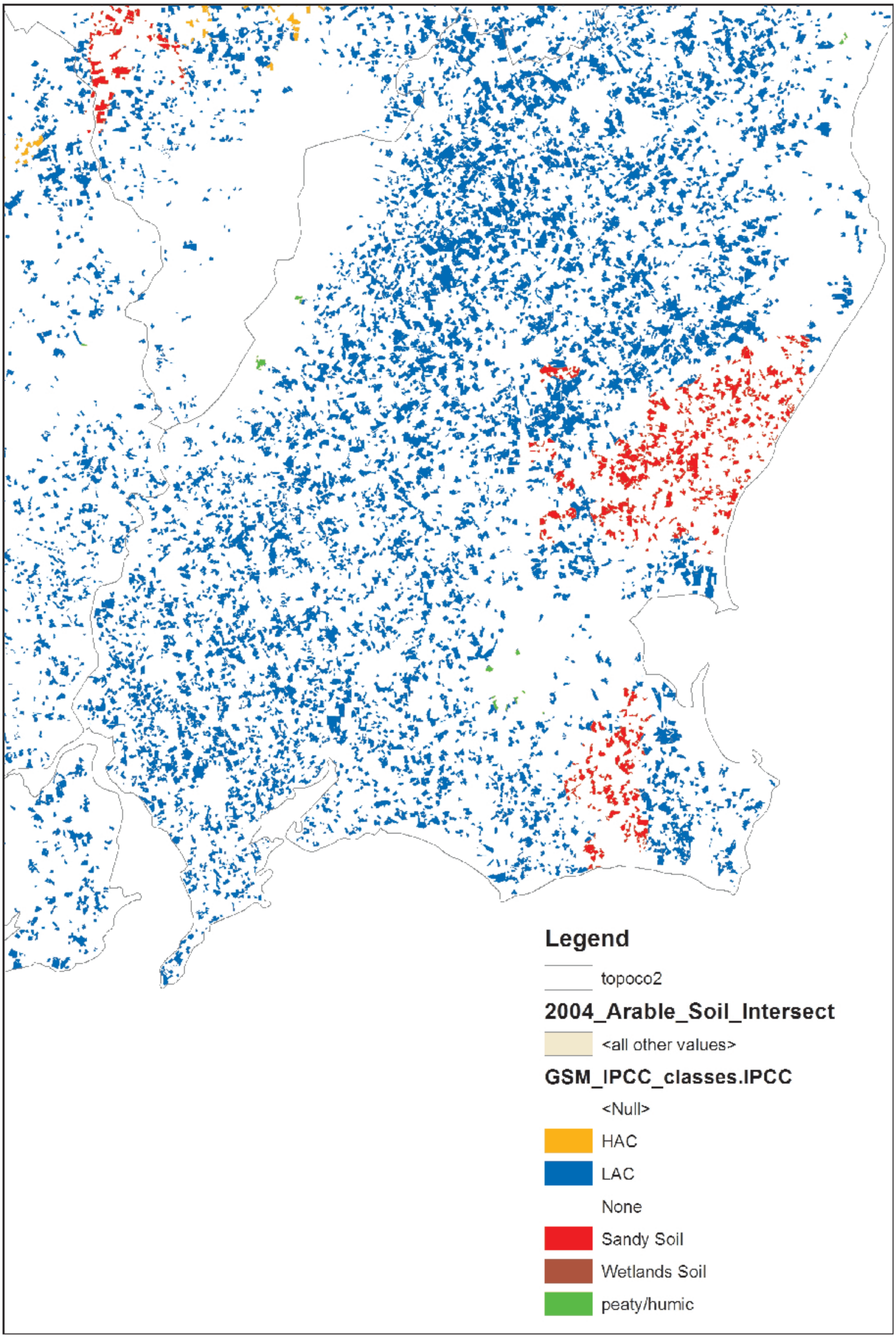


Figure 4.3. Land parcel information system showing croplands and soil type.

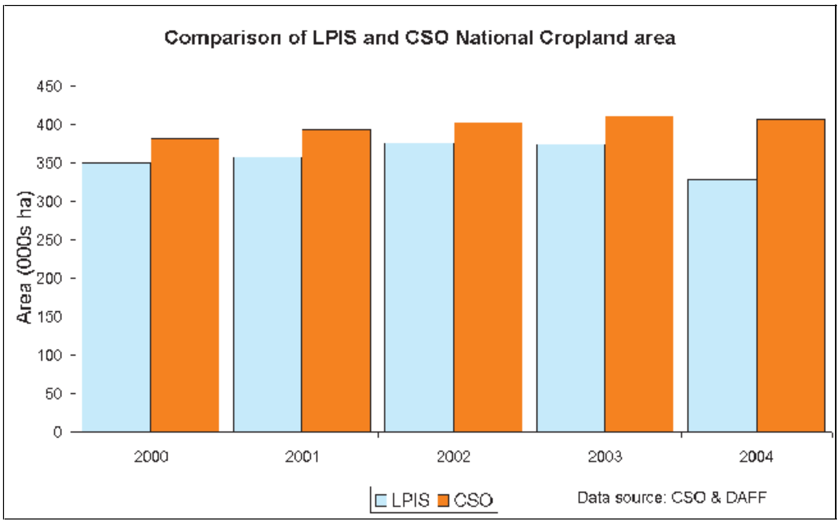


Figure 4.4. Comparison of total cropland area according to the CSO and the LPIS.

Cropland on mineral soils. Emissions from liming have been fully accounted for within the grasslands land-use class. Since, under the default Tier 1, there is no distinction made between lime spreading on grasslands or croplands, with the same emission factor for both, the total emission due to lime spreading is the same regardless of whether account is taken of lime between land-use classes.

$$\Delta C_{CC_{Soils}} = \Delta C_{CC_{Mineral}} + \Delta C_{CC_{Organic}} + \Delta C_{CC_{Lime}} \quad (4.1)$$

Equation 4.2 shows the expression for estimating change in carbon stocks within organic stocks used for crops. The default emission factor is 1.0 t C/ha for drained organic cropland soils.

$$\Delta C_{CC_{Organic}} = \Sigma_C (A \times EF)_C \quad (4.2)$$

4.3 Set-Aside

Set-aside is treated in the same way as a conversion of cropland to grassland, but is discussed within the croplands land-use class, as the grass is only a temporary cover.

Table 4.1 gives the land-use factors used to estimate the annual change in soil carbon stock during the set-aside period.

4.4 Land Converted to Cropland

Lands converted to croplands are estimated based on the changes in the CSO figures for annual area under crops. The land-use management factors used in the analysis are shown in Table 4.2. In reality, the sum of the other factors listed in the IPCC GHG would apply to the Irish situation. Therefore, there is probably a wider range of tillage (F_{MG}), and input (F_I) applicable to croplands in Ireland. However, there are insufficient data on the impacts of farming practices to establish a reliable breakdown of the crop areas within different tillage and input regimes. Therefore the median IPCC GPG factor has been chosen in each case. It is probable that there is a high incidence of the 'High-with manure input' regime; however, there is also a probable high incidence of 'Full Tillage' regime, each offsetting the other in terms of aggregate impact on total soil carbon in croplands.

The annual change in carbon due to land in transition to cropland (LC) is estimated using the expression in Eqn 4.3, where LB refers to living biomass.

$$\Delta C_{LC} = (\Delta C_{LC_{LB}} + \Delta C_{LC_{Soils}}) \quad (4.3)$$

4.5 Living Biomass

Similar to the treatment of grasslands in transition, the change in biomass is estimated as the difference between biomass before and immediately after conversion to croplands plus a year of biomass growth (Eqn 4.4).

$$\Delta C_{LC_{LB}} = A_{Conversion} \times (L_{Conversion} + \Delta C_{Growth}) \quad (4.4)$$

where $L_{Conversion} = C_{After} - C_{Before}$.

The conversion of grassland to cropland requires the removal, or ploughing under, of existing biomass prior to the planting of crops. Therefore, there is complete loss of living biomass. The conversion of grassland to cropland

Table 4.1. Relative carbon stock change factors for set-aside.

Croplands to set-aside					
Mineral soils			**Inventory period 20 years**		
Cropland SOC_{Before}					
Cold temperate moist	**SOC_{ref}**	**F_{LU}**	**F_{MG}**	**F_I**	**SOC_{Before}**
LAC	85.00	0.71	1.09	1.11	73.02
Sandy soils	71.00	0.71	1.09	1.11	60.99
Set-aside SOC_{After}					
Cold temperate moist	**SOC_{ref}**	**F_{LU}**	**F_{MG}**	**F_I**	**SOC_{After}**
LAC	85.00	0.82	1.16	1.11	89.75
Sandy soils	71.00	0.82	1.16	1.11	74.96
					t C/year
	Annual		ΔSOC	LAC	0.84
				Sandy soils	0.70

Table 4.2. Relative stock change factors for croplands (F_{LU}, F_{MG}, F_I) (over 20 years) for different management activities on cropland (extract from IPCC GPG Table 3.3.4, LULUCF GPG).

Factor value type	Level	Temperature regime	Moisture regime	GPG revised default	Error (%)	Description
Land use (F_{LU})	Long-term cultivated	Temperate	Wet	0.71	12	Represents area that has been continuously managed for >20 years, predominantly annual crops
Tillage (F_{MG})	Reduced	Temperate	Wet	1.09	6	Primary and/or secondary tillage but with reduced soil disturbance (usually shallow and without full soil inversion). Normally >30% coverage by residues at planting
Input (F_I)	High, without manure	Temperate and tropical	Wet	1.11	10	Represents significantly greater crop residue inputs due to production of high-residue yielding crops, use of green manures, cover crops, improved vegetated fallows, frequent use of perennial grasses in annual crop rotations, but without manure applied

represents a net loss of carbon stocks from living biomass to the atmosphere (see Tables 4.3 and 4.4).

4.6 Soils

Equation 4.5 is used to estimate change in carbon stock of soils converted to cropland.

$$\Delta C_{LC_{Soils}} = \Delta C_{LC_{Mineral}} + \Delta C_{LC_{Organic}} + \Delta C_{LC_{Lime}} \quad (4.5)$$

All liming is assumed to occur on grasslands, and so is not included in the analysis of croplands. Equation 4.5 reduces to Eqn 4.6. The assumption is incorrect, but has no impact on total carbon emissions from LULUCF, as lime spread on grassland is assumed to emit CO_2 at the same rate as that spread on cropland. However, the contribution of grassland to carbon emissions within LULUCF is overestimated, and the contribution of croplands underestimated as a consequence.

$$\Delta C_{LC_{Soils}} = \Delta C_{LC_{Mineral}} + \Delta C_{LC_{Organic}} \quad (4.6)$$

4.7 Results for Croplands

Figure 4.5 shows the results of the estimate of changes in carbon stocks for croplands. The time series shows croplands to have considerable variability. The increase in soil carbon, a sink for atmospheric carbon, is due to croplands being put to set-aside, during which they sequester carbon under grass. The loss of carbon from both living biomass and soils in more recent years reflects a net increase in area under croplands.

Table 4.3. IPCC GPG default living biomass present on land converted to cropland in the year following conversion (extract from IPCC GPG Table 3.3.8).

Crop type	Carbon stock in biomass after 1 year (ΔC_{Growth})	Error range (%)
Annual cropland	5	75
Perennial cropland	2.1	75

Table 4.4. Change in biomass in conversion from grassland to cropland.

DM/ha	DM_{Before}	12.00
0.50	C_{Before}	6.00
	C_{After}	0.00
	$L_{Conversion}$	–6.00
t C/ha	ΔC_{Growth}	5.00

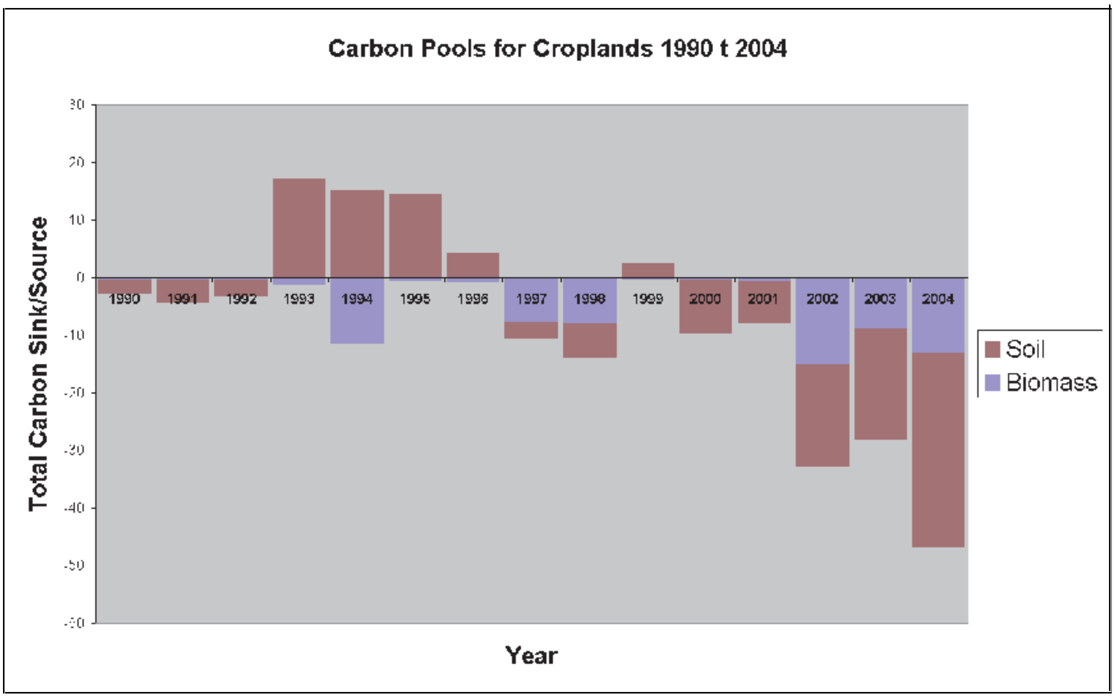


Figure 4.5. Changes in carbon pools for croplands, 1990–2004.

5 Wetlands and Peatlands

Between 14% and 19% of Ireland is wetlands, much of which are in a natural or semi-natural state. In the natural saturated state, wetlands are a source of methane emissions, derived from the slow process of anaerobic decay of organic material. Globally, natural wetlands contribute significantly to total GHG emissions to the atmosphere. Natural emissions, however, are not considered under normal UNFCCC reporting procedures. There is strong evidence that some 75% of Irish wetlands are not pristine, but have suffered human interventions at some stage in the last few hundred years. However, it can be shown that most of these wetlands have re-established themselves as living bogs, and therefore the greenhouse gases emanating from them derived from natural processes which occur without human intervention.

It is assumed that there is no conversion of any other land-use type to wetlands. There is no regeneration of wetlands after forestation, for example.

In this analysis, it was found to be useful to differentiate explicitly between wetlands and peatlands. Wetlands in this analysis are those areas of organic soils that are not currently drained or actively managed, but can be considered to be natural, living boglands. Peatlands are those areas of wetlands that have been drained in preparation for, or are in the process of being exploited for, extraction of peat. Bord na Móna is a semi-state body charged with the profitable management of Ireland's peatland resources. The drainage of wetlands for conversion to forestry, or other land use, is accounted for within the appropriate chapter.

5.1 Data Sources for Peatlands

Peatland areas are derived from Bord na Móna data given in Table 5.1, and Fig. 5.1 shows the time series of estimated peatland areas actively exploited in the period 1985–2005. Bord na Móna is the largest operator in the peat exploitation sector and is the monopoly supplier of peat to the peat-fired energy plants operated by the Electricity Supply Board, in Ireland. Estimates of peat extraction activity by other operators in the sector,

Table 5.1. Wetland and peatland areas owned by Bord na Móna.

Peatland category	Bord na Móna – Peatland (ha)					
	1985	1991	1996	2001	2006	
	85/90	91/95	96/00	01/05	Vegetation cover	CO_2 emissions
Active production bog	49,715	48,961	46,319	43,761	None	Minimal
Production reserve (drained)	16,250	14,100	12,772	5,930	Heather	Small
Fringe bog (undrained)	8,300	8,300	8,300	8,300	Heather-dominated bog vegetation	Small
Partially drained	3,090	3,090	3,090	3,090	Typical bog vegetation	Neutral/Sink
Undrained intact bog	4,150	2,508	0	0	Intact bog vegetation	Sink
Cutaway						
Forestry (plantation)	2,500	4,000	4,000	4,200	Conifers	Sink
Forestry (natural)	0	100	800	2,235	Birch/Willow	Neutral
Wetlands (acidic)	483	483	2,703	9,044	*Eriophorum*, *Carex*, *Sphagnum*	Neutral/Sink
Wetlands (alkaline)	250	1,250	2,150	3,200	*Typha*, *Phragmites*, Open water	Minimal
Lands sold/transferred	2,541	1,946	2,658	374		
Total owned (at end of period)	84,738	82,792	80,134	79,760		

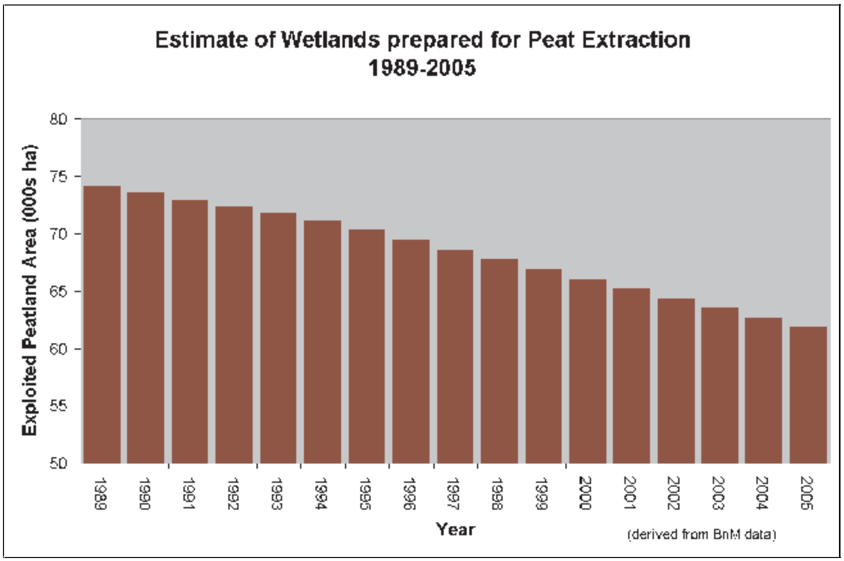


Figure 5.1. Estimated total area of exposed peatland 1990–2005.

including private industry and domestic turbary are based on expert opinion from Bord na Móna.

The total area of exposed peatland is the sum of the Bord na Móna area, the estimated private industrial peatlands and the area of peatlands exploited by private domestic users.

5.2 Methodology for Peatland Soils and Biomass

There is limited guidance in the IPCC GPG regarding Tier 1 treatment of peatlands. There is considerable flexibility in how human activity on peatlands might be addressed. Most of the research on wetlands GHG activity has concentrated on pristine, natural, undrained wetlands. The LULUCF is interested in assessing GHG activity associated with drained, disturbed and degraded wetlands. This lack of relevant scientific data has compelled the authors of the IPCC GPG to offer only provisional advice on the treatment of wetlands in LULUCF.

The LULUCF classification for exploited peatland is Wetlands remaining Wetlands, and is viewed as a change in land management. The IPCC GPG recommends the estimation of GHG emissions from those peatlands that have been modified for the purpose of peat extraction. In Ireland, peat extraction is undertaken by three groups: Bord na Móna, private industry and private owners of turbary rights.

5.3 Exploitation of Peatlands by Private Owners with Turbary Rights

Hand-cutting of peat is a long-established traditional fuel source in Irish rural areas. The tradition is in decline, a process encouraged in recent years by government wetlands conservation grants given to the owners of turbary rights in return for undertakings not to exploit the bog. At its height, during the 1940s and 1950s, when more conventional fuels were in short supply, the non-industrial private-sector removal of peat from Irish peatlands is estimated to have been *c.* 6 million tonnes per year.

There is anecdotal evidence that private cutting of peat is sensitive to the relative cost of other fuels. When conventional fuel prices rise, certain people take advantage of their turbary rights, and cut turf for private, domestic consumption.

New technologies have entered the non-industrial private sector, for example the so-called 'sausage machine', which makes peat extraction less labour- and cost-intensive. These factors may be encouraging increased exploitation of private turbary rights. Figure 5.2 shows the local impact of sausage machine extraction on a raised bog in the west of Ireland. Note the drainage channel to the right of the image. Peat is extracted down to the level of the water table. The biomass layer has been discarded in a heap in the foreground of the image. This is not the traditional practice. The extracted peat is left to dry in small turf stacks, seen in the background. Bord na Móna estimates that currently 1 million tonnes of peat is

Figure 5.2. Non-commercial peat extraction.

removed by hand-cutting ever year. This translates to an exposed peatland area of approximately 400 ha. Appendix D gives the details of this estimate.

5.3.1 *Non-commercial extraction of peat (hand-cut, cutover bogs)*

Non-commercial extraction occurs once a year, during the early summer, as the turf sods require a significant drying period. As with industrial extraction, it is necessary to drain the peatland in preparation for cutting. A normal part of the summer routine of work is the maintenance of existing gravity drainage systems and excavation of new channels where necessary.

Extraction of peat proceeds in a stepwise manner. First the biomass layer is removed. Then the first turf layer is removed. This is the most difficult layer to remove manually. Figure 5.3 illustrates the stages of peat extraction. An interesting point to note is that the living biomass layer, the top-sod, is not removed from the bog, Traditionally, the plant material removed from the new cut of the bog is placed directly over the last fully exploited cut ridge. Therefore at any given time, there is a constant area of exposed peat.

5.4 Industrial Exploitation (Cutaway Bog)

5.4.1 *Bord na Móna*

Bord na Móna exploits large areas of raised peatland using industrial methods. It owns a total peatland area of *c.* 80,000 ha, of which *c.* 70,000 ha are in production. The remaining area has been drained and is held in reserve for future exploitation. Industrial exploitation of peatland differs greatly from traditional hand-cutting methods. Initially, the biomass layer is removed, leaving the peat exposed, over a large area. A thin layer of peat is removed from the surface during the annual harvest, of the order of 10–15 cm per annum. The average depth of a commercial raised bog prior to exploitation is 4–10 m; therefore an industrial peatland area is actively exploited over a number of decades.

Bord na Móna ceased the purchase and drainage of additional peatlands in 1980. Thereafter, the principal operator in the sector has not drained additional wetland areas during the UNFCCC reporting period.

5.4.2 *Private industrial peat extraction*

A number of smaller industrial companies operate throughout the country. Private industrial operators have a 12.5% share of the peat products market, and therefore it is reasonable to assume that they must exploit a peatland area approximately 12.5% the size of that worked by Bord na Móna.

5.5 Methods of Industrial Exploitation

The methods employed to extract peat are worth exploring in terms of the potential for carbon loss to the atmosphere directly from the soil. The carbon emissions to the atmosphere during the burning of peat are estimated in the energy sector reporting procedure.

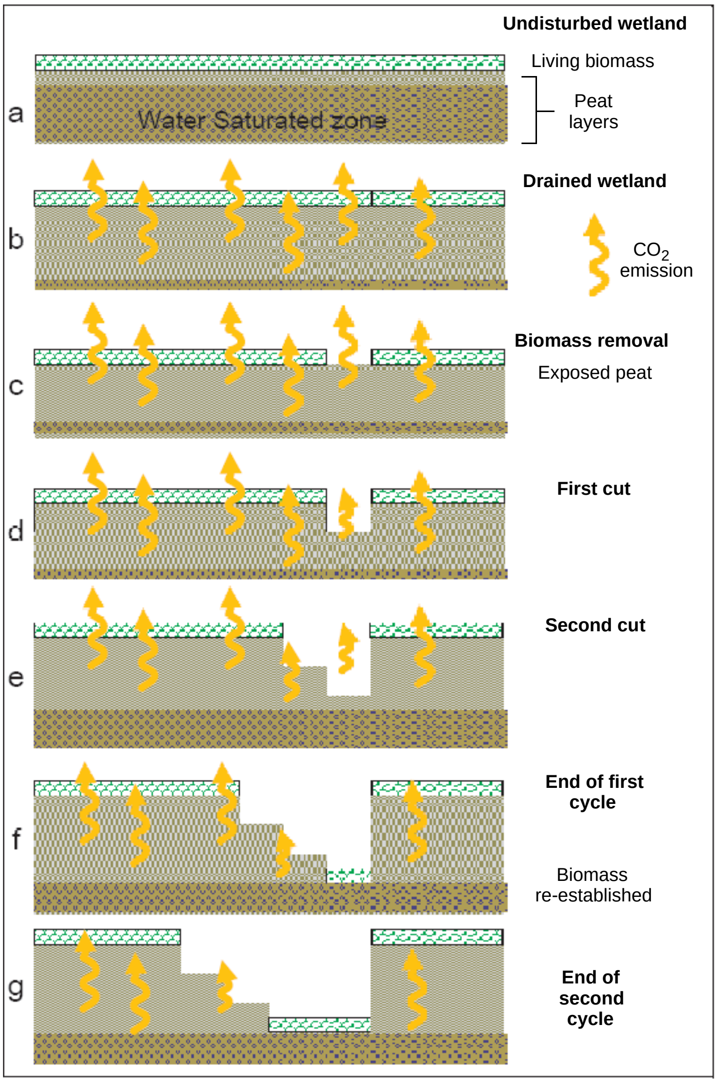


Figure 5.3. Stages in the non-commercial extraction of peat.

Industrial exploitation of peatland proceeds in three stages followed by after use:

- Drainage
- Biomass removal
- Peat extraction
- After use.

A detailed description of the industrial methods are given in Appendix E.

5.6 Methodology for Assessing GHG Emissions from Peatlands

The two processes that determine the carbon loss to the atmosphere during the procedure of peatland exploitation are drainage and biomass removal. Biomass removal is a once-off event occurring at the commencement of peat extraction. Drainage is an ongoing activity, commencing, in the case of Bord na Móna, at the time of purchase of the land, but in all cases a few years before the commencement of peat extraction. Drainage can continue for a period after the extraction of peat has stopped. After-use drainage can be managed or unmanaged. When after use falls under the heading of land-use change, such as transition to forestry or grassland, then it is assumed that the drainage of the organic soil continues and that the carbon loss is accounted for appropriately.

In the methodology used here, it is assumed that in a system that is unmanaged, drainage ceases in the year of abandonment and the system reverts to a non-anthropogenic classification, and therefore is not to be included in the inventory analysis.

$$C_{Emissions_{WW_{Peat}}} = \left(\Delta C_{WW_{Peat_{LB}}} + \Delta C_{WW_{Peat_{Soils}}}\right) \times 10^{-3} \quad (5.1)$$

where $\Delta C_{WW_{Peat_{LB}}}$ is the change in carbon stocks in living biomass (t C/year) and $\Delta C_{WW_{Peat_{Soils}}}$ is the change in carbon stock in soils (t C/year).

5.7 Biomass Removal

The carbon loss from removal of biomass is estimated by multiplying the area of newly exposed peatland by the average biomass carbon content. All biomass is removed. There is no re-establishment of biomass.

$$\Delta C_{LW_{Peat_{LB}}} = \Sigma A_i \times CF \times (B_{After} - B_{Before}) \quad (5.2)$$

where $\Delta C_{LW_{Peat_{LB}}}$ is the annual change in carbon stocks in living biomass in lands converted to peat extraction (t C/year), A_i is the area of land converted annually to peat extraction from original land use (i) (ha/year), B_{Before} is the above-ground biomass DM immediately before conversion to peat extraction (t DM/ha), B_{After} is the above-ground biomass DM immediately after conversion to peat extraction (default = 0) (t DM/ha), and CF is the carbon fraction of DM (default = 0.5) (t DM).

Peatlands exploited by industrial methods tend to be rain-fed raised bogs, and therefore nutrient-poor. There are no data to determine the proportion of peatlands that might be nutrient-rich. Therefore, an assumption that all exploited peatlands are nutrient-poor will yield an overestimate of carbon loss, consistent with the IPCC GPG.

5.8 Peatlands Restoration

During the restoration of peatlands to wetlands, it is assumed that saturation of the exposed peat occurs in the year of transition, and that biomass is restored to full condition over the same period. It is assumed that drainage of the peatland has ceased and that GHG emissions from the soil are natural.

These are quite optimistic assumptions. However, advice from Bord na Móna, based on its experience of restoration projects, is that the re-establishment of natural vegetation is rapid.

The formulation of carbon uptake due to the re-establishment of biomass is the reverse of the biomass removal equation (Eqn 5.2). Biomass before restoration is zero, biomass after restoration is 3.0 t C/ha.

5.9 Carbon Loss from Soil

The Tier 1 method has been modified to exclude abandoned areas that are still drained, as there are no reliable data on these areas. Peatlands finished in industrial production are adapted to after use, which either returns the peatland to a flooded saturated state, or converts it to another land use such as forestry. Peatlands abandoned by the non-industrial sector are undocumented. It can reasonably be assumed that the non-industrial sector exploits the peat down to the level of summer-time water table. Therefore, after abandonment, the peatland area is effectively water saturated (Table 5.2).

$$\Delta C_{WW_{Peat_{Soils,\ extraction}}} = A_{Peat_{Npoor}} \times EF_{Peat_{Npoor}} \quad (5.3)$$

where $A_{Peat_{Npoor}}$ is the area of nutrient-poor organic soils managed for peat extraction, excluding abandoned areas in which drainage is still present, and $EF_{Peat_{Npoor}}$ are the emission factors for CO_2 from nutrient-poor organic soils managed for peat extraction (t C/ha/year).

Figure 5.4 shows the estimated carbon stock changes in living biomass and soil for wetlands. The annual accumulation of biomass shows the net effect whereby the restoration of peatlands to wetlands after commercial exploitation is greater than the biomass removal from new extraction sites. Figure 5.5 shows the time series of estimated total carbon stock changes from exploited peatland areas since 1990.

Table 5.2. Emission factors and associated uncertainty for organic soils after drainage.

Region/Peat type	Emission factor (t C/ha/year)	Uncertainty (t C/ha/year)
Boreal and Temperate		
Nutrient-rich (EF_{Nrich})	0.2	0–0.63
Nutrient-poor (EF_{Npoor})	1.1	0.03–2.9

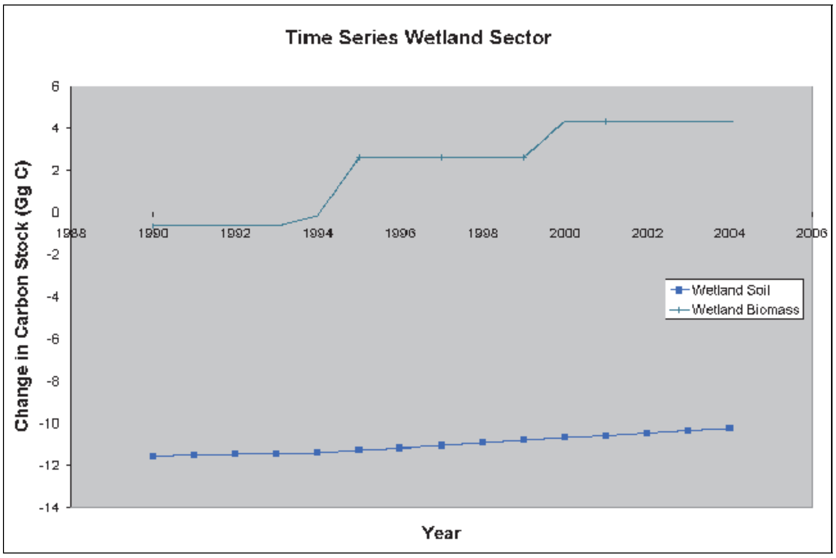


Figure 5.4. Carbon stock changes in biomass and soil for exploited peatlands.

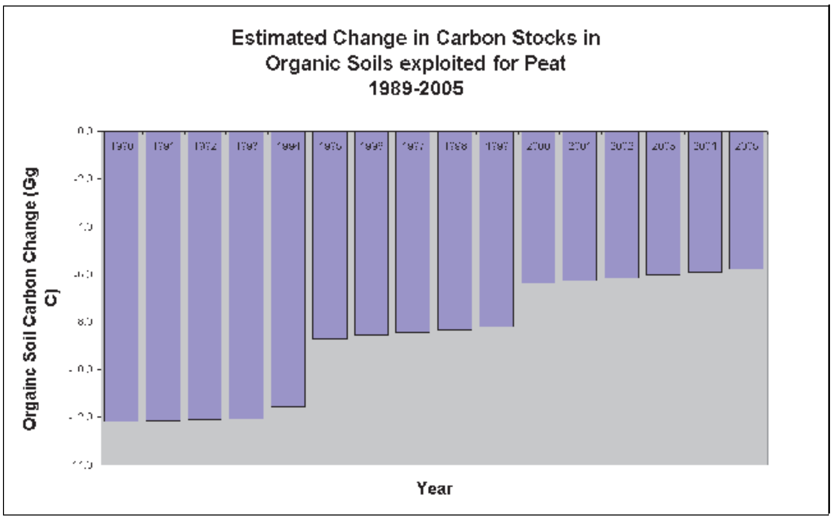


Figure 5.5. Total carbon loss to the atmosphere from exploitation of peatlands.

6 Settlements

Ireland has experienced significant economic growth over the last decade. Coupled to this growth has been a major expansion of the transport infrastructure, as well as unprecedented building construction in the domestic, government and commercial sectors.

Activities in the settlements sector are discussed under two headings:

1. The construction of dwellings and non-dwelling buildings

2. Roads and other transport infrastructure.

An estimate of carbon exchange from urban living biomass to the atmosphere has been omitted from this analysis (e.g. urban parks, roadside trees, etc.). Further research and data compilation are required on this topic before a reliable estimate of this carbon stock can be attempted.

6.1 Data Sources for Settlements

Settlements are derived from CORINE and the CSO and the Department of the Environment, Heritage and Local Government (DEHLG), the National Roads Authority (NRA) and the ESB new household connections data. Figure 6.1 shows the annual area of land converted to settlement since 1990, broken down into the three main activities in the sector: dwelling construction, non-dwelling construction and major road construction.

The initial area of settlements in Ireland is derived from the CORINE 1990 data. This is the sum of all land covers representing urban, suburban, infrastructure and mining classes. It is assumed that transition to settlements is immediate (i.e. it occurs in less than 1 year). All GHG activity associated with a change in land use to settlement occurs in the year of conversion.

The Tier 1 approach assumes that there are no emissions or sinks of GHG associated with Settlements remaining Settlements. Therefore the initial estimate of total settlements, based on CORINE 1990, need not be accurate when reporting GHG activity for the period 1990–2004. However, the quality of the data tracking new settlement activity since 1990 is critical.

All construction undertaken in Ireland is administrated through the local authority planning system, which operates within the DEHLG. A land developer seeks planning permission from the local authority, which is granted upon inspection of the detailed plans submitted.

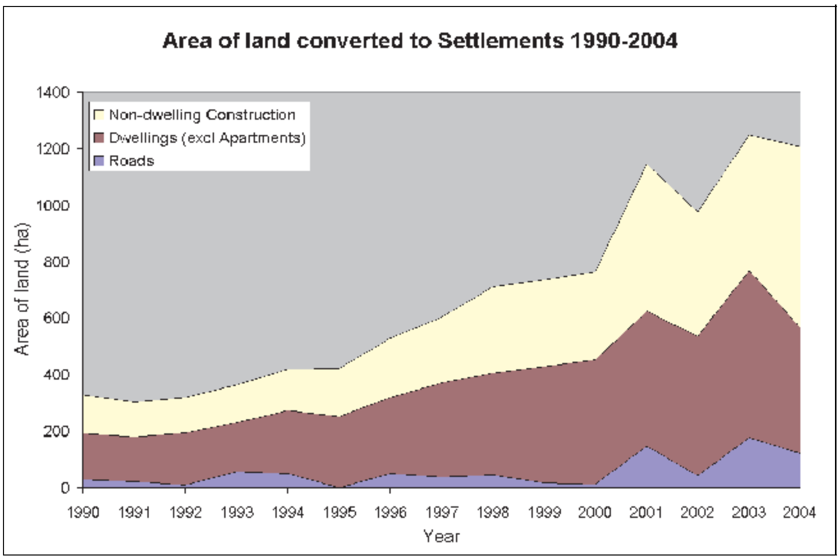


Figure 6.1. Time series of land area sealed in conversion to settlements: 1990–2004.

6.2 Data Sources for New Building Construction

Data from the CSO include annual dwelling and non-dwelling construction statistics. The data include information on the number of planning permissions granted for various types of buildings and the average floor area. Floor area is not the same as surface footprint. A number of assumptions were needed to convert the floor area to an estimate of land converted to settlement, for example the proportion of single, and multi-storey buildings, the proportion of building taking place on greenfield sites, and construction on existing urban sites.

The DEHLG has collated additional data on new dwelling types since the mid-1990s. Table 6.1 and Fig. 6.2 show the breakdown under the headings of new bungalow, detached, semi-detached, terrace and apartments during the period 1994–2004. The number of new households is based on new connections to the national grid, supplied by the Electricity Supply Board.

Some interesting trends appear in the analysis of the housing data. The number of new houses completed per year in Ireland has been high relative to the size of population, and shows little sign of abating. There has been particularly strong growth in the number of semi-detached houses built since 2000. Figure 6.3 shows that the floor area of new houses has gradually increased. This would imply that housing density has decreased, a conclusion that is supported by the concurrent decline in new terrace construction. However, it could be argued that the old demand for terrace housing is being met by construction of apartments, which has increased in the same period, and constitutes higher density housing.

In general, it is reasonable to assume that the building of apartments has occurred within existing urban areas, and therefore does not constitute land-use change. Bungalow and detached dwellings tend to be constructed on greenfield sites, as 'one-off' housing or as part of new suburban estates. The majority of semi-detached housing also tends to be on greenfield sites creating new suburban estates, but a significant number may be the

Table 6.1. Data sources for settlement data.

Type	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Bungalow	6,077	6,748	6,645	7,451	7,343	8,221	9,070	9,029	8,870	8,934	6,665
Detached	4,447	5,462	8,583	9,552	9,631	12,962	14,828	15,471	13,157	13,276	13,516
Semi-detached	9,362	10,395	10,023	12,511	14,368	14,036	14,470	14,006	18,633	23,522	37,736
Terraced	1,442	1,558	1,400	1,626	1,469	1,697	2,158	3,070	4,997	7,848	2,531
Apartment	5,112	6,009	6,670	7,302	9,137	9,196	8,886	10,626	11,638	14,839	16,106

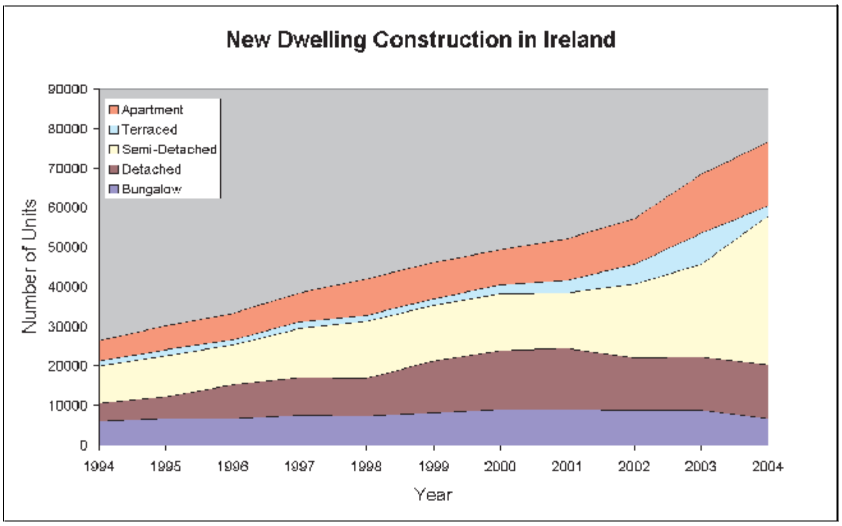


Figure 6.2. New dwelling construction in the period 1991–2001.

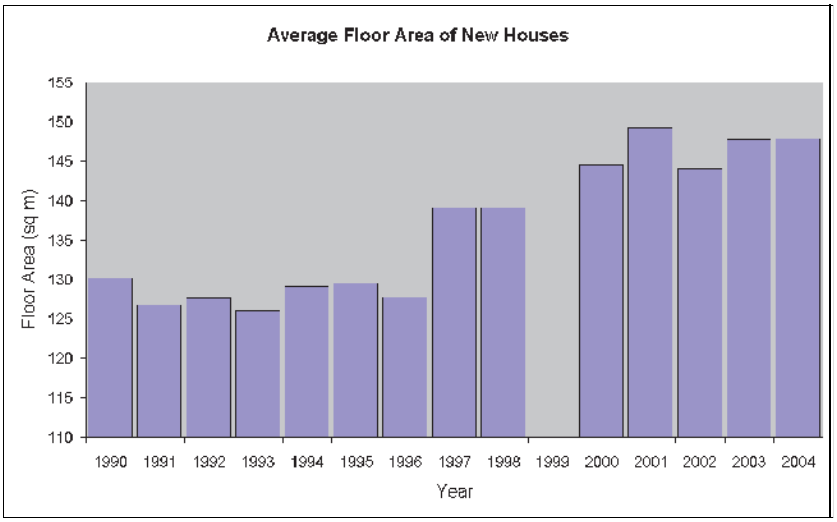


Figure 6.3.Trends in the floor area of new houses in Ireland 1990-2004 (no data for 1999).

redevelopment of sites within existing urban areas. Similarly, new terrace development is likely to be redevelopment of existing urban fabric.

Non-dwelling construction can occur on greenfield sites or within the existing urban areas. There have been significant ‘out-of-town’ developments across the country, including new shopping centres and their associated car-park facilities. Also, new business park developments have grown on the outskirts of many of the larger towns in Ireland. This greenfield development has been offset by certain government schemes regarding urban renewal, whereby investment has been encouraged within ‘run-down’ areas of town and city centres.

In this analysis, it has been assumed that 50% of all new dwelling and non-dwelling construction has occurred on greenfield sites. It is assumed that greenfield development has occurred on grassland, and on all soil types excluding wetlands.

6.3 New Dwellings and Non-Dwelling Buildings

It is assumed that the previous land use for all new greenfield dwelling and non-dwelling construction was grassland. Therefore, the biomass lost is just the removal of the grass cover. The IPCC GPG default grassland living biomass for grassland for this climate zone is 12.0 t DM/ha. The total carbon loss due to the removal of biomass is therefore 6.0 t C/ha.

6.4 Data Sources for New Building Construction

New road construction in Ireland is administrated by the NRA. A brief summary of the provenance of the NRA is given below.

“The National Roads Authority was formally established as an independent statutory body under the Roads Act 1993, with effect from 1 January 1994.

The Authority's primary function, under the Roads Act 1993, is 'to secure the provision of a safe and efficient network of national roads'. For this purpose, it has overall responsibility for planning and supervision of construction and maintenance works on these roads.” http://www.nra.ie

The NRA has responsibility for major infrastructural development of the Irish road network under the National Development Plan. The NRA undertakes to publish annual statistics on new roads in the planning stages and project completions, available on their website (http://www.nra.ie/RoadSchemeActivity/).

New roads are constructed to conform to specific minimum standards, including minimum width of road surface. Table 6.2 shows the standard lane widths for each road type. Knowing the length of new road of each type completed in a given year allows an estimate of the area ‘sealed’ under roads. It is assumed that the change in land use/cover occurs in the year of completion, rather than the year the road project was announced, or received

Table 6.2. Standard width of new roads by type in Ireland (NRA).

	Total width (m)
Motorways	
Standard	27.6
Wide	38
Extra lane	45
Slip lanes	
1 lane	13.5
2 lane	16.3
Slip lanes diverge	
2 line	10.5
Mainlines	
Reduced single	7.5
Standard single	9.8
Wide single	12.5
Standard dual	13.1
Wide dual	20.5
Slip roads	
1 lane	14
2 lane	16.3
Slip roads diverge	15

planning permission. This may lead to a minor inconsistency in tracking land cover and land use, as larger road projects can take a number of years after the initial 'breaking' of new ground to completion. However, these larger infrastructural road projects tend to progress in stages, with 2- to 3-year construction periods.

Secondary or non-national roads are constructed and maintained by local authorities. Ireland has the longest length of non-national roads per capita (25.7 km per 1,000) of all EU countries (EU average 8.5 km per 1,000). There is little demand for new secondary road building, and the main activities on these roads are maintenance and improvement (road straightening and road widening).

As a first-order estimate of land-use change due to road construction it is reasonable to ignore non-national road activity. The area of land converted to roads is therefore confined to those projects undertaken by the NRA.

6.5 Methodology Settlements

The IPCC GPG Tier 1 method does not require one to consider carbon loss from soils during the conversion of lands to settlement. It is assumed that the establishment of settlements (including buildings and roads) represents complete soil sealing, with no change in the carbon stocks in the soils. Only loss of living biomass needs to be considered.

6.6 Data Sources for Road Construction

The national proportion of each land-use type according to CORINE 1990 is used to disaggregate the total annual road area completion reported by the NRA. Table 6.3 shows the proportional breakdown of CORINE 1990 land cover, excluding wetlands. It is assumed that wetlands are unsuitable for the construction of roads. Only the loss in biomass is considered.

Table 6.3. CORINE 1990 previous land uses for areas converted to settlements excluding wetlands[1].

Previous land use	Proportion
Forest	0.09
Grass	0.79
Arable	0.07
Other	0.05

[1]Based on the assumption that wetlands are not converted to settlements.

Although the areas of land converted to roads are quite modest, that proportion of the area that was previously forest is estimated to have contained a considerable mass of carbon stored in the biomass.

Figure 6.4 shows the average biomass per hectare of forest in Ireland during the period 1990–2004. It is interesting to note that biomass per hectare shows a gradual downward trend. This is due to the increasing proportion of very young forests within the national forest area. Obviously, younger forests have yet to amass a considerable store of biomass, and therefore the average biomass decreases although the total biomass in forestry increases. The biomass loss per hectare from grasslands, croplands and other lands is relatively small.

Future consideration needs to be given to the fate of topsoil removed from construction sites, and the impact on SOC for these soils. Removal of soil represents a considerable disturbance, and the potential for carbon loss is probably greater than the loss during conversion to tillage for example, as the entire depth of topsoil is 'turned over'. For completeness, the NRA will be approached for access to their GIS and survey data on new roads' projects in order to generate a more accurate estimation of previous land use.

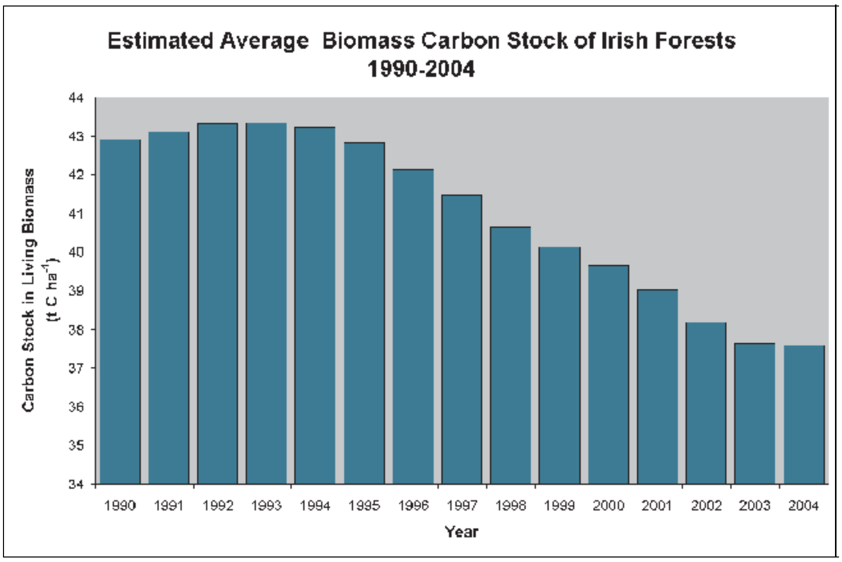


Figure 6.4. Change in average biomass carbon stock per hectare in Irish forests.

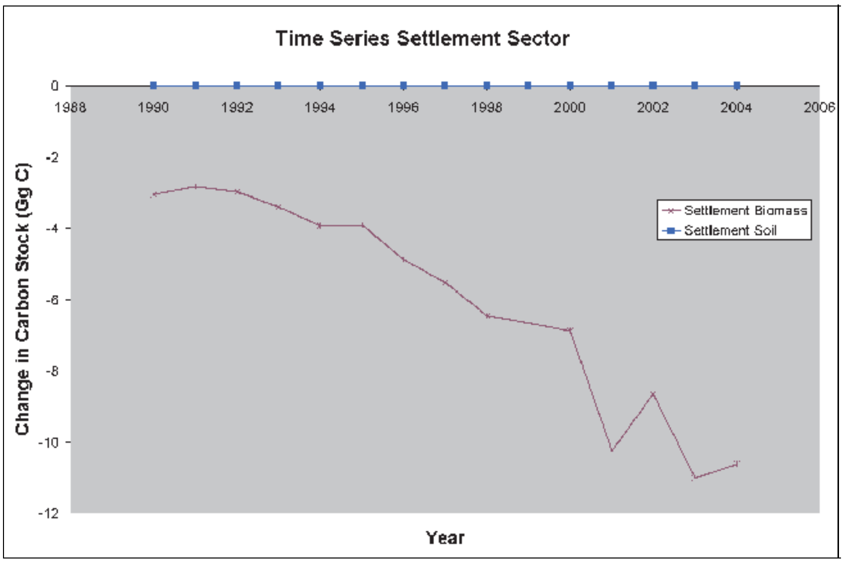


Figure 6.5. Change in carbon stocks for settlements, 1990–2004.

Settlements remaining Settlements have not been considered in this analysis. It is assumed that the soils are sealed, without any exchange of carbon to the atmosphere, and that there is no re-establishment of biomass. This is a reasonable assumption given that the estimate of land area converted to settlements is the actual footprint of the constructions, and excludes grass verges, gardens, etc. Figure 6.5 shows the resultant estimate of changes in carbon stocks due to growth in the settlement sector in Ireland over the UNFCCC reporting period. Although not a key source within the LULUCF sector, there have been significant increases in areas of soil sealing due to urbanisation over this period.

7 Other Land

7.1 Data Sources for Other Land

The Other Land is derived from the residual analysis of all the other land-use categories. There is no definitive programme of monitoring land classes that come under the Other Land category in Ireland. It is assumed that Other Land constitutes the rest of the land area not already accounted for under the other land-use categories for which reliable data are available. Other Land is assumed to be in a natural or semi-natural state. More especially, it is assumed that any land in transition to Other Land is unmanaged for human exploitation. It consists of unexploited wetlands, natural grasslands and mountainous regions.

Areas leaving the Other Land category are assumed to have been unimproved grassland. The underlying soil type is assumed to reflect the proportion of IPCC soil classes in the country as a whole.

All lands converted to Other Land are assumed to have been degraded grasslands, no longer required for rough grazing.

It is assumed that organic soils entering the Other Land land-use category have previously undergone some anthropogenic management. In particular, it is assumed that it was drained. During the default transition period of 20 years, it is assumed that the drainage is still effective and that carbon emissions continue. The emission factor for these organic soils is taken to be 0.25 t C/ha/year, which is the IPCC GPG default emission factor for drained grasslands on organic soils.

7.2 Methodology for Other Land

It is assumed that there is no change in the living biomass of lands in transition to Other Land. The change in soil carbon reflects the transition, over 20 years, from degraded grassland to unimproved grassland, a transition that tends to increase soil carbon.

Any inferred transfer of lands into Other Land from Grassland is the abandonment of rough grazing lands, that is, unimproved grassland. The land cover remains unaffected, it remains unimproved grassland. However, Grassland returning to Other Land from rough grazing is classified as initially degraded, to take account of the possible effects of overgrazing and animal trampling of vulnerable soils. Although the transition could also accurately be classified as Grassland remaining Grassland with a change in management, the designation as a land-use change between Grassland and Other Land reflects the change in status between agricultural and non-agricultural usage. It should be noted, however, that the area of Grassland/Other Land conversion is inferred from changes in the Grassland data. As stated previously, direct monitoring of Other Land usage does not occur.

The area of lands converted to Other Land is divided into organic and mineral soil areas based on the national natural grassland (unimproved grassland) derived from CORINE 1990 and the GSM. Table 7.1 shows this breakdown. As with the other land-use classes, changes in soil carbon for organic and mineral soils are based on different methods.

Likewise, Table 7.2 shows the proportions of mineral soils under natural grasslands derived from the overlay of CORINE 1990 on the GSM.

Table 7.1. Proportion of natural grassland on mineral and organic soils.

Soil group	CORINE 1990 Natural Grasslands	Proportion
Mineral soils	73,998.34	0.81462
Organic soils	16,839.49	0.18538

Table 7.2. Proportion of natural grasslands on mineral soil types.

Soil type	Soil	Mineral subgroup	Proportion
HAC	1	9,562.219	0.13
LAC	2	18,875.46	0.26
Peaty/Humic	3	44,349.68	0.60
Sandy	4	1,210.99	0.02

7.3 Mineral Soils

The expression used to estimate the change in soil carbon stock in mineral soils in transition to Other Land is shown in Eqn 7.1.

$$SOC = SOC_{Ref} \times F_{LU} \times F_{MG} \times F_I$$

$$\Delta SOC = \frac{(SOC_{After} - SOC_{Before})}{T}$$

$$\Delta C_{OG_{Mineral}} = \Delta SOC \times Area \qquad (7.1)$$

where T is the transition period.

Table 7.3 shows the estimation of ΔSOC for the conversion of rough grazing to ungrazed, natural grassland. for the four mineral soil types, based on the reference SOC and land use F factors shown.

7.4 Organic Soils

Similar to the treatment of organic soils in previous chapters, carbon loss from drained organic soil is simply the product of the area of organic soil in transition to Other Land times the default emission factor.

The reverse assumption is used for Other Land converted to Grassland. When the CSO statistics suggest an increase in grassland, it is assumed that any deficit in supply from conversion from the other land classes is made up by a conversion of unimproved grassland in the Other Land class to unimproved grassland that is rough grazing.

Figure 7.1 shows the time series of estimated changes in carbon stock in the Other Land class from 1990 to 2004. Invariably, a transition from degraded rough grazing to ungrazed grassland leads to an increase in the soil carbon content, and so the transition to Other Land is a carbon sink. The results are heavily dependent on the validity of the assumption that the ‘abandoned’ grassland, i.e. the land no longer required for agricultural use, is unimproved and degraded. Abandoned improved grasslands would have an SOC before conversion higher than the natural grassland type. However, it is reasonable to assume that improved grassland is not abandoned lightly, but would follow a period of less intense management, during which the grassland would tend towards rough grazing prior to abandonment.

There are limited data on conversion of land from Forest Land, Cropland, Settlements or Wetlands to the Other Land class, that is, abandonment. Forest Land and

Table 7.3. Default soil organic carbon stocks during transition from rough grazing to unimproved grassland.

Cold temperate moist			Transition period 20 years		
Rough grazing to non-grazed					
Mineral soils					
From grazed unmanaged grassland					
Degraded grassland SOC_{Before}					
	SOC_{Ref}	**F_{LU}**	**F_{MG}**	**F_I**	**SOC_{Before}**
HAC	95.00	1.00	0.95	1.00	90.25
LAC	85.00	1.00	0.95	1.00	80.75
Peaty/Humic	115.00	1.00	0.95	1.00	109.25
Sandy	71.00	1.00	0.95	1.00	67.45
To unmanaged grassland SOC_{After}					
	SOC_{Ref}	**F_{LU}**	**F_{MG}**	**F_I**	**SOC_{After}**
HAC	95.00	1.00	1.00	1.00	95.00
LAC	85.00	1.00	1.00	1.00	85.00
Peaty/Humic	115.00	1.00	1.00	1.00	115.00
Sandy	71.00	1.00	1.00	1.00	71.00
					t C/year
			ΔSOC	HAC	0.24
				LAC	0.21
				Peaty/Humic	0.29
				Sandy	0.18

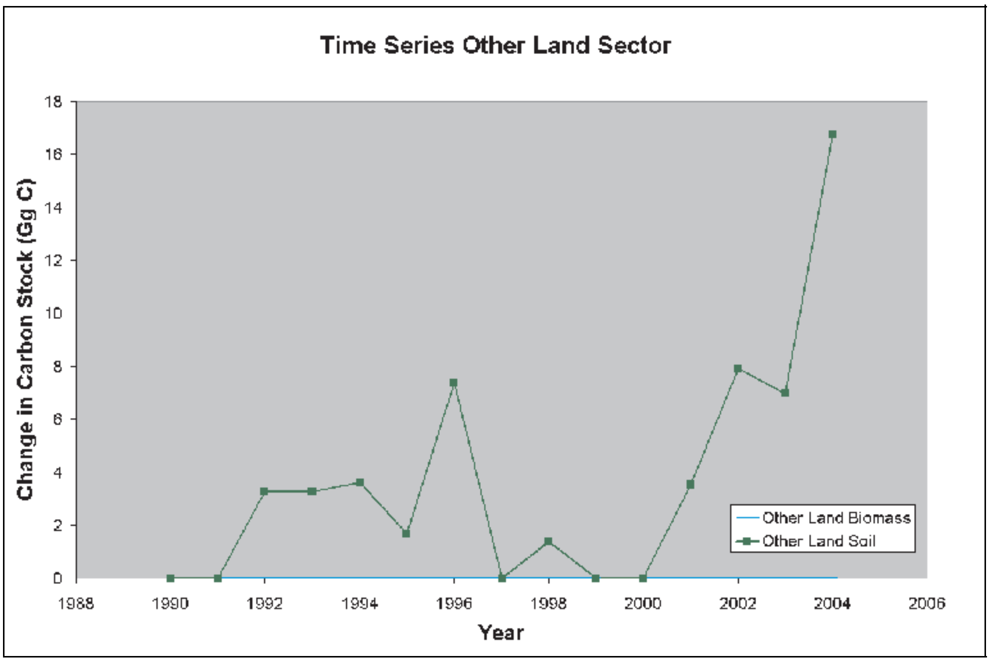


Figure 7.1. Change in total carbon stocks in the Other Land class.

Settlements both are increasing their total area, and so may require a transfer of land out of the Other Land class. Any change in Cropland is assumed to be mirrored by changes in improved grassland, as it is unlikely that the good quality land used for crops would be abandoned and left unmanaged, but rather would convert to managed grassland. The conversion of peatlands to other use after extraction is confined to Forest Land and Grassland; otherwise the peatlands revert to wetlands, which is the same land class (Wetlands remaining Wetlands) but with a change of management.

8 Summary of Carbon Change in the LULUCF Sector

This chapter presents a summary of the estimated carbon emissions and sinks from each land use within the LULUCF and places them in the context of overall total activities within LULUCF.

Carbon uptake by forest biomass is the largest single activity within the LULUCF sector, as can be seen in Figs 8.1 and 8.2. Changes in forest biomass have been estimated using Tier 3 methods by COFORD. However, a substantial part of the carbon uptake by forest biomass is offset by a release of carbon from newly afforested soils. Gradually, as the new forests mature, the soils will recover to an equilibrium state. The magnitude of the forest soil carbon release is reflective of the high level of afforestation that has taken place in Ireland in recent decades, and is a unique feature of the Irish situation. It is recommended that the estimate of carbon loss for forest soils be progressed to a Tier 2 method in line with its relative importance within the LULUCF sector.

Using the Tier 1 methodology, grassland land use in Ireland constitutes a key source of atmospheric carbon under two activities: CO_2 release due to the spread of lime and the loss of carbon from grassland soils. The exchange of carbon from grassland soils is estimated based on annual changes in reported areas of improved agricultural grasslands, and as such is quite variable. In some years, the exchange is reversed and grassland soils are estimated to be a sink of carbon. The estimate is based only on grasslands undergoing changes in management and land use. There is some evidence to suggest that managed grasslands in Ireland have the potential for longer-term carbon sequestration. It is recommended that further research be undertaken to investigate this question, and that the estimation of carbon exchange from grassland soils be progressed to a higher Tier methodology. It is also recommended that investigation be made as to whether the Tier 1 methodology for CO_2 release due to lime spreading is valid in an Irish context.

A comparison of the 1990 and 2004 sectoral breakdown of LULUCF carbon exchange shows only modest changes in most sectors. The fall in CO_2 emissions due to liming is a reflection of the sale of lime in 2004. There is considerable inter-annual variation in lime sales. In this regard, 1990 was more or less an average year.

The increase in carbon release from cropland soils reflects a more sustained increase in lands converted to croplands over the last decade, as can be seen in Fig. 8.3. However, there is some uncertainty as regards the future of tillage in Ireland, with the impact of the recent collapse of the sugar-beet industry (~10% croplands) yet to appear in the inventory estimates.

The time series of total carbon change within the LULUCF sector is shown in Fig. 8.4. The apparent trend is from a source of atmospheric carbon for much of the 1990s to a sink of carbon in more recent years. However, this hides a complex dynamic between the dominant sink, forest biomass, and the three main carbon sources: forest soils, grassland soils and liming. Progress needs to be made towards more accurate assessment of these three sources of carbon in order to be more confident of the trend seen here.

8.1 General Comments and Data Gaps

The estimates of GHG emissions due to land use, land-use change and forestry presented in this document represent a necessary first step towards an accurate and robust national inventory of these emissions. The analysis is consistent with the Tier 1 methodology outlined in the IPCC GPG (1996), and involved the compilation of information from a wide variety of disparate data sources. Considerable effort has been taken to ensure the ‘completeness’ of the estimate of carbon exchange within the LULUCF sector for Ireland.

Much effort is required to progress towards a higher Tier methodology to ensure that the reported emissions more closely reflect Irish conditions. Particular effort is required for the key sources identified in the analysis.

The key sources identified within the LULUCF sector are:

- Forest biomass
- Forest soils
- Lime spreading
- Grassland soils.

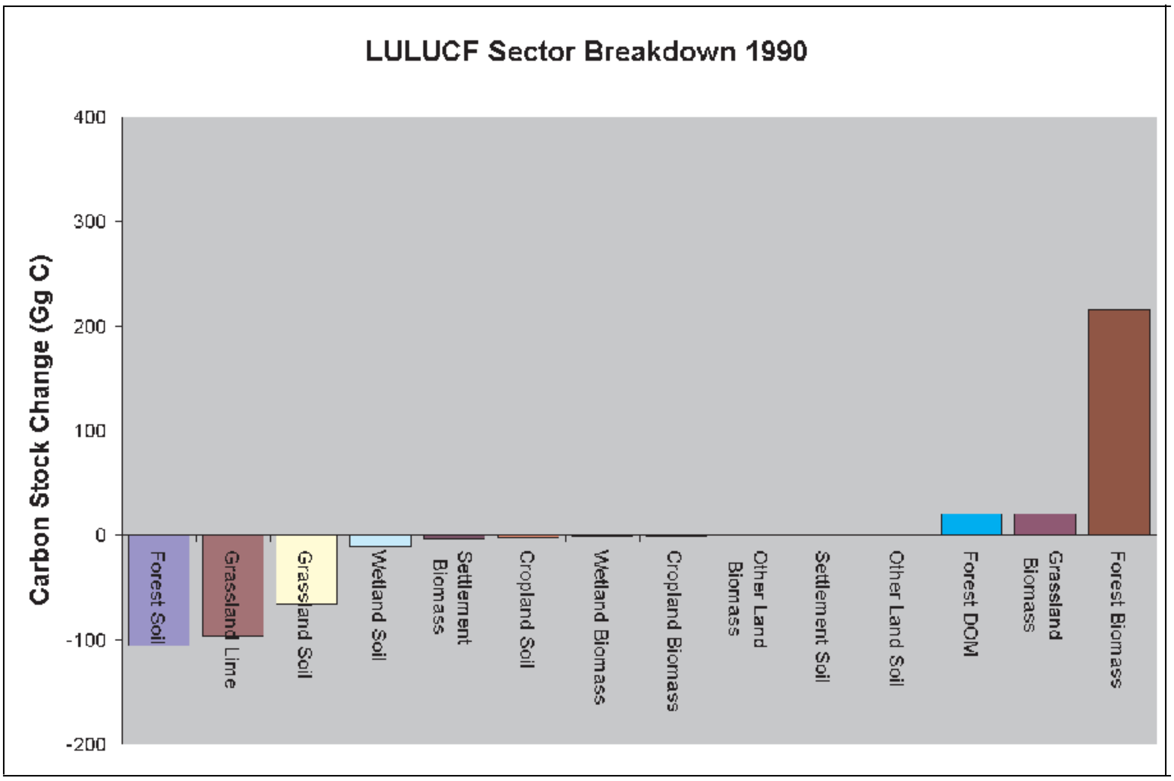


Figure 8.1. Breakdown of carbon emission according to activity, 1990.

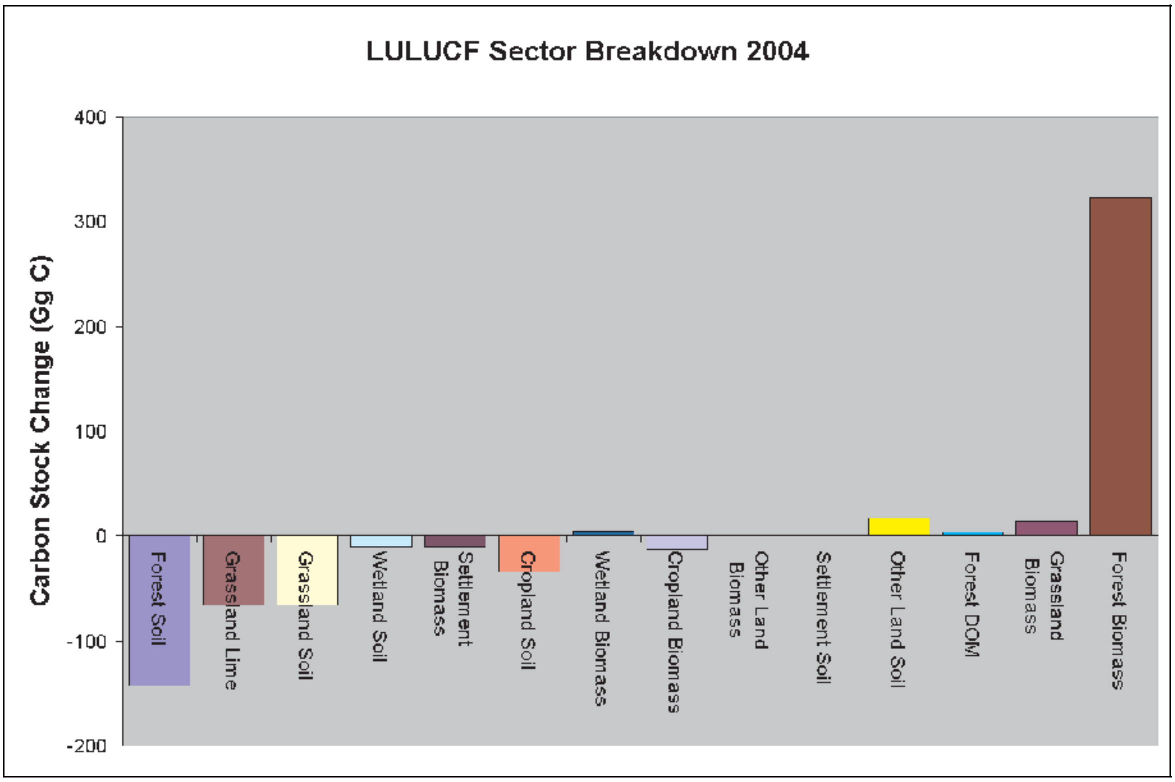


Figure 8.2. Breakdown of carbon emission according to activity, 2004.

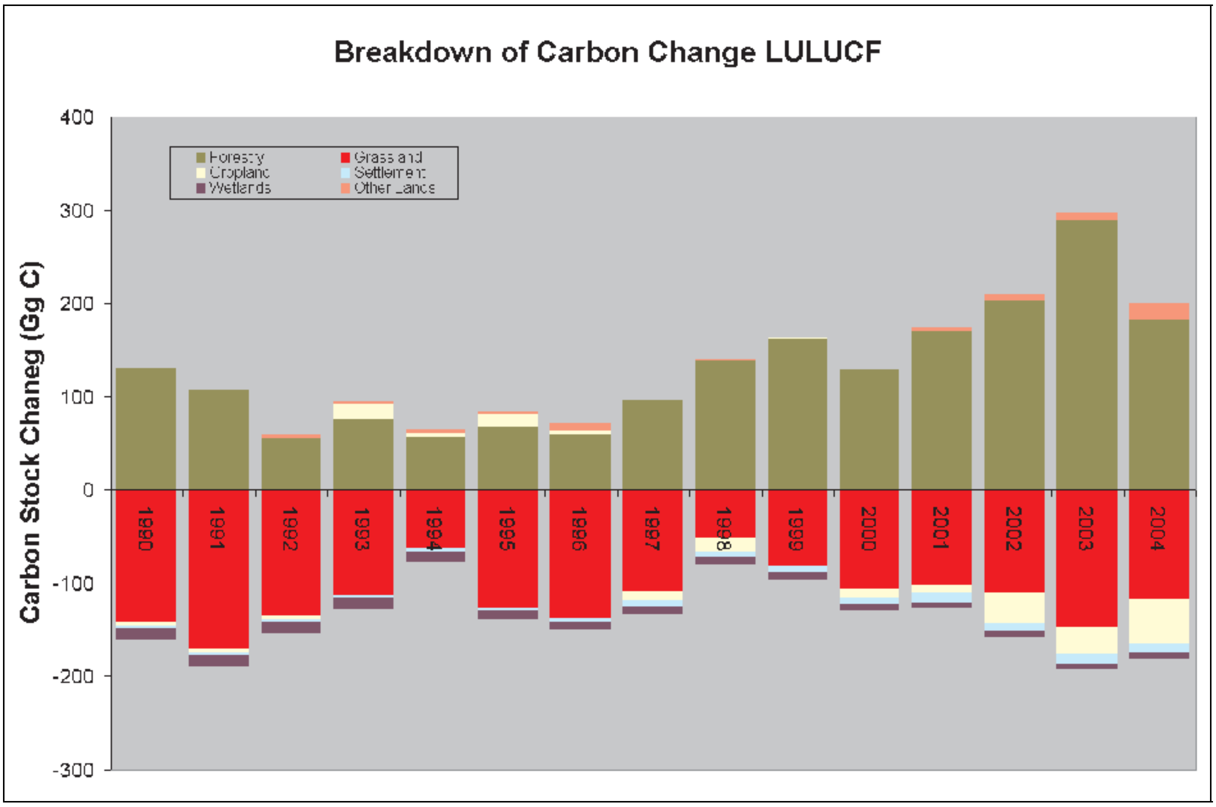


Figure 8.3. Time series of carbon stock change within LULUCF classes.

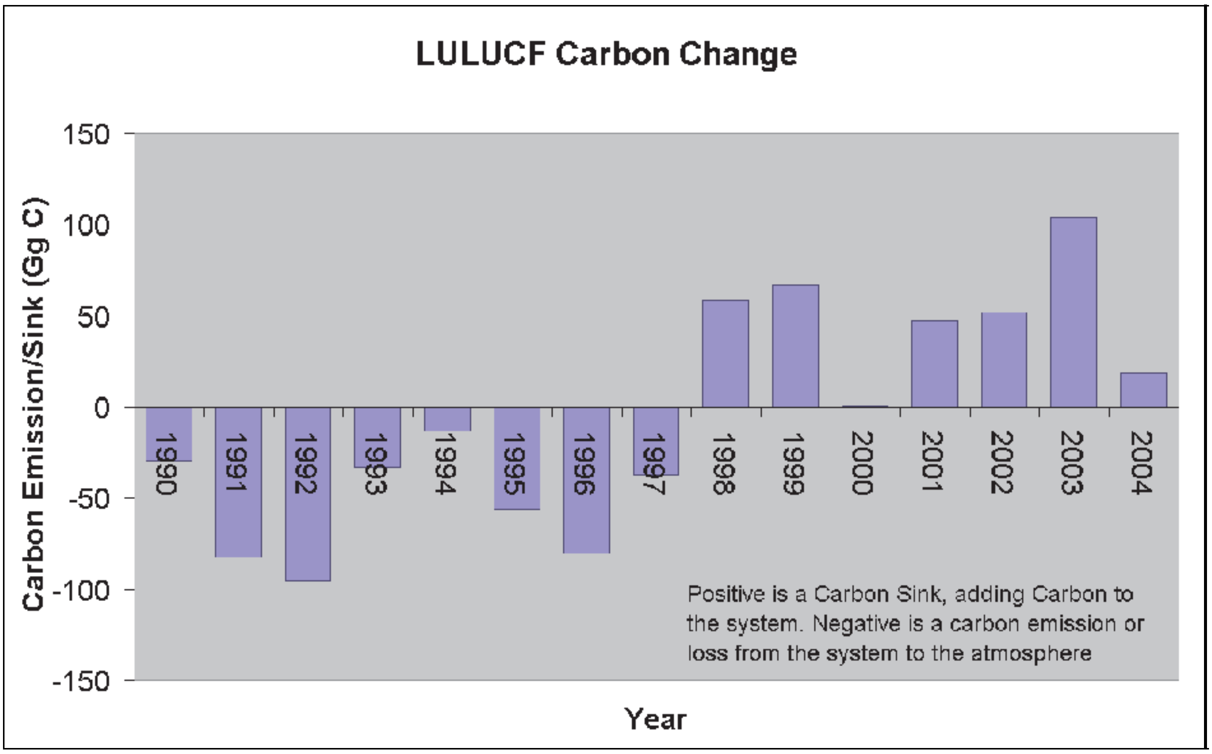


Figure 8.4. Net carbon stock change LULUCF, 1990–2004.

Croplands and Wetlands are quite minor land-use activities, but with some concern as to the potential for their achieving greater importance in the future, either to revised methodologies or changing patterns of land use. Settlements and Other Land are demonstrated to be minor activities in the context of LULUCF.

In order to progress towards better methodologies, certain gaps in data and in scientific understanding need to be addressed. Existing high-quality soil carbon data are sparse, and do not represent an adequate range of land-use practices in Ireland. Research is ongoing to address this issue. The IPCC classification of just six soil classes does not allow full exploitation of existing soil data for Ireland. A soil classification more suited to the soils found in Ireland, linked to existing soil property databases, would significantly reduce uncertainties in the analysis.

Liming has been identified as a key source of emissions within the LULUCF sector. It is recommended that research be done with regard to the validity of the default emission factor under Irish conditions.

An estimate of emissions of N_2O have been omitted from this document as they are optional within the UNFCCC reporting requirements and there is some ambiguity in the outline methodology proposed in the IPCC GPG.

There are occasions within the current analysis where the distinctions between different land-use classes are vague. This does not impact on the total LULUCF GHG values, but may move significant areas of land from one class to another. The most problematic are distinctions between Wetlands and Other Land and between Grassland and Other Land. The present solution is unsatisfactory, but reflects the limitations of the data used to estimate the extent of land-use change.

The problem is the availability of reliable data. Activities and situations without explicit economic value tend to be poorly monitored. The CSO and the Department of Agriculture and Food can produce reliable and consistent national annual figures for croplands and agriculturally important grasslands, but can offer little with regard to unexploited grasslands.

Similarly, the Forest Service office in the Department of Agriculture and Food and Coillte, the state forestry agency, can provide comprehensive information of commercial afforestation throughout the country, with databases extending back several decades. However, amenity, park, roadside and private domestic or small-scale tree plantation, and other activities having no economic value, are poorly documented. The issue of tree planting in urban areas is discussed in the GPG, but there are not sufficient data to address the issue for Ireland. Urban trees are not a key source, and so not a priority concern for inventory development.

The current representation of land-use change into and out of grassland and croplands is inadequate. It assumes a homogeneity of farmer behaviour that is difficult to justify. The detailed analysis of the LPIS database is beginning to reveal some, more complex, patterns of behaviour, which will allow more realistic assumptions to be formulated.

There is no GIS used in the Settlements land-use class. This is a shortcoming of the present analysis. Detailed spatial information for new road construction may be available from the NRA. In recent years, local authorities have invested strongly in GIS regarding domestic and non-domestic buildings. Subject to confidentiality constraints, these data may be available for inventory purposes.

It should be noted that the carbon stored in Irish peaty soils and wetlands is probably vulnerable to climate change. The projected climate change impacts on Ireland include drier, warmer summers, which would threaten rain-fed water tables which sustain Irish bogs. Therefore, much of Ireland's soil carbon stocks may be under threat, not from human activity *per se*, but from climate change itself, with little potential for mitigation of the carbon loss.

Occasionally, conditions favourable to the outbreak of bog fires occur. The fires generally occur on wetlands drained for extraction of peat, and so the fires can be described as resulting from anthropogenic activity, although obviously they are inadvertent and unwelcome events. However, statistics on the volume of peat consumed in these fires are difficult to compile. The risk of such fires may increase in a drier summer climate, and may expand to include unexploited wetlands.

Periodic scrub and heath burning is undertaken in upland and Atlantic coastal regions to maintain open rough grazing lands or to maintain heather cover for game. The practice occurs in Ireland, though it is not as widespread as, for example, in Scotland.

Hedgerows are an important and significant part of the Irish landscape. Webb (1988) estimated that 1.5% of Irish land cover is hedgerow, and as such may represent a significant biomass store.

Appendix C presents a brief discussion of the biomass stocks in Irish hedgerows, and the potential change in carbon stocks associated with hedgerow removal.

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Appendix A Relationships between LULUCF and CORINE Land Classes, and GSM and IPCC Soil Classes

Table A1. Relationship between CORINE land-cover classes and LULUCF land-use class used in this analysis.

Forest Land	Grassland	Cropland	Settlements	Wetlands	Other Land
Broadleaf forest	Pastures	Non-irrigated arable	Continuous urban fabric	Inland marshes	Estuaries
Conifer forest	Land primary agriculture, significant natural vegetation[1]	Land primary agriculture, significant natural vegetation[1]	Discontinuous urban fabric	Peat bogs	Moors and heaths
Mixed forest	Natural grassland		Industrial sites		Beaches
Translation woody scrubland	Complex cultivation pattern[2]	Complex cultivation pattern[2]	Road and transport		Bare rock
			Port areas		Sparsely vegetated
			Airports		Burnt areas
			Dump site		Salt marshes
			Construction		Salines
			Green urban		Intertidal zones
			Sport and leisure		Mineral extraction
					Watercourses
					Coastal lagoons

[1]The area under 'Land primary agriculture, significant natural vegetation' is divided equally between Grassland and Cropland LULUCF classes.
[2]The area under 'Complex cultivation pattern' is divided equally between Grassland and Cropland LULUCF classes.

Table A2.Relationship between General Soil Map associations and IPCC soil classes and relative abundance (Tomlinson 2005).

Soil	Basin peat	Brown earth	Brown podzolic	Gley	Grey brown podzolic	Lithosol	Lowland blanket peat	NA	Podzol	Regosols	Rendzina	Unclassified	Upland blanket peat	Sum	% Sum
High activity clay		2	77	824	1						91			995	5.7%
Low activity clay		2,155	1,913	2,527	3,864	1			160	21		70		1,0711	60.9%
Sandy soils		44	120		273	361			6	1		1		806	4.6%
Peaty/Humic soils			6	197		240			1,233	1		10		1,687	9.6%
Peat	939						955						1,078	2,972	16.9%
NA								287						287	1.6%
Unclassified						27						98		125	0.7%
														0	0.0%
Sum	939	2,201	2,116	3,548	4138	629	955	287	1,399	23	91	179	1,078	17,583	100.0%
	5.3%	12.5%	12.0%	20.2%	23.5%	3.6%	5.4%	1.6%	8.0%	0.1%	0.5%	1.0%	6.1%	100.0%	

Soil proportion	Basin peat	Brown earth	Brown podzolic	Gley	Grey brown podzolic	Lithosol	Lowland blanket peat	NA	Podzol	Regosols	Rendzina	Unclassified	Upland blanket peat	% Sum
High activity clay	0	0	4	23	0	0	0	0	0	0	100	0	0	6
Low activity clay	0	98	90	71	93	0	0	0	11	91	0	39	0	61
Sandy soils	0	2	6	0	7	57	0	0	0	4	0	1	0	5
Peaty/Humic soils	0	0	0	6	0	38	0	0	88	4	0	6	0	10
Peat	100	0	0	0	0	0	100	0	0	0	0	0	100	17
NA	0	0	0	0	0	0	0	100	0	0	0	0	0	2
Unclassified	0	0	0	0	0	4	0	0	0	0	0	55	0	1

Appendix B Discussion of Discrepancy between Forest Service Afforestation Data, the LPIS and CORINE

Since 1970, the official records maintain that some 190,000 ha have been afforested. The GIS estimates only 160,000 ha. Only a relatively small proportion of the uncertainty can be ascribed to the assumption of flat terrain within the GIS. Although significant plantation occurs on hillsides, a 30° slope is required to account for the 30,000 ha (20%) mismatch. With a 20° slope, only 6% of the mismatch can be attributed to terrain.

The LPIS and derivative Forest Service GIS data have some reliability and quality assurance issues. The Forest Service derives its GIS shapefiles from the LPIS database. The shapefiles are exported to ARCMAP format from the native LPIS system. Some concern has been expressed regarding the exactness of the export algorithm, and considerable effort has been made after translation to 'clean' the raw export shapefile, leading to a more accurate afforestation map. The errors are common GIS artefacts, such as spiking overlay misalignment giving rise to slithers of land.

Even with editing, the GIS data show that a significant discrepancy exists between the official afforestation figures, based on grant application forms, and which are audited, and the total area of afforestation derived from the GIS.

The area difference is approximately 20%. The discrepancy is probably acceptable within the uncertainties inherent in both GIS analysis and the official record areas planted. The average official parcel area is 4.3 ± 5.7 ha. As can be seen from Fig. B1, the size of afforestation plots recorded in the Forest Service data is skewed towards small parcel areas. The GIS calculated average parcel area is 3.4 ± 4.8 ha.

CORINE has a minimum mapping unit of 25 ha. Afforestation on good-quality soils tends to occur on relatively small land parcels, and would not constitute the dominant land use within a 25-ha zone. In effect, the forest area is neglected, and subsumed into the dominant land class, usually grassland. Also, in Ireland, larger afforested plantations tend to be on poor peat soils. Therefore CORINE underestimates afforestation in general, and overstates the proportion of afforestation on peat. The impact of the minimum mapping units on identified forested areas can be see in Fig. B2.

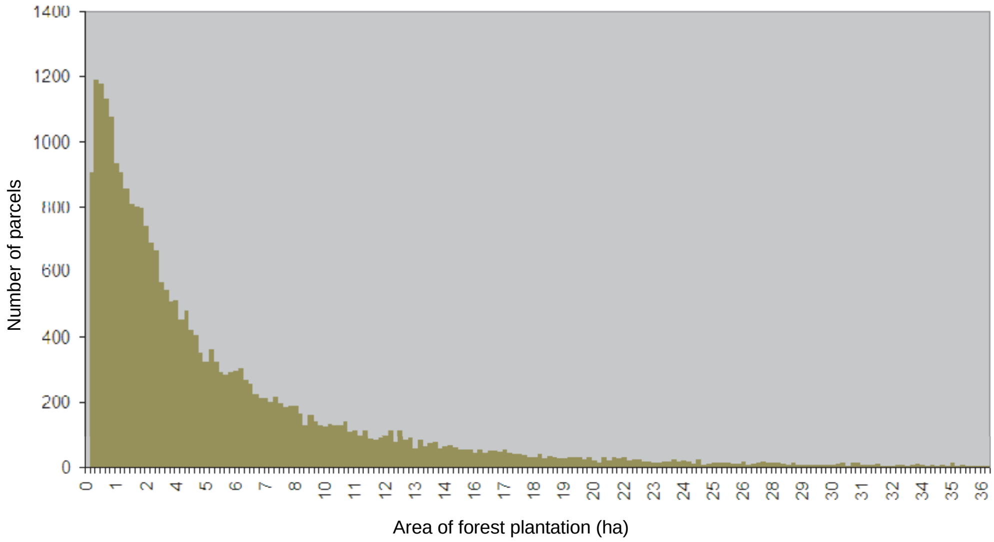

Figure B1. Land parcel areas for afforestation since 1990.

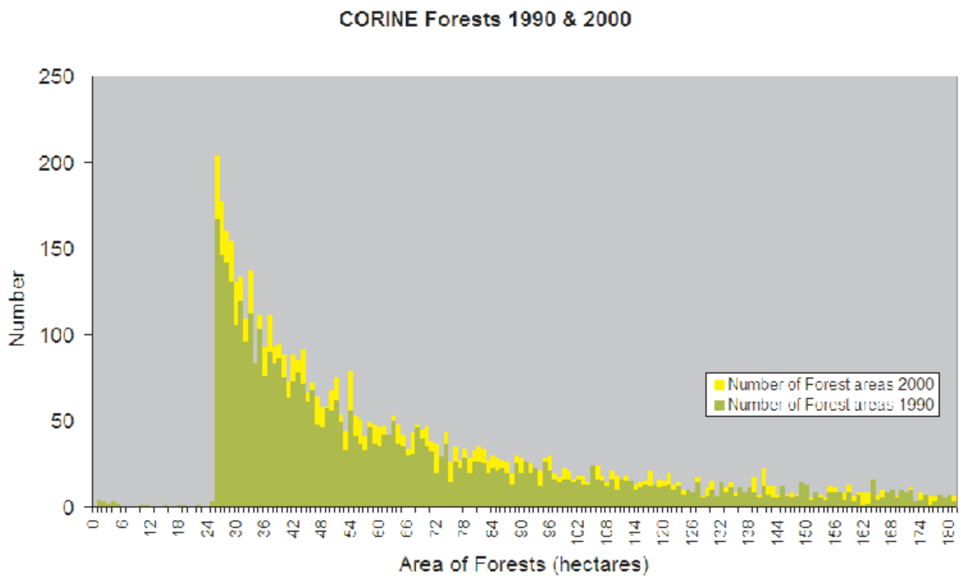

Figure B2. CORINE forests 1990 and 2000.

Appendix C Hedgerows

Hedgerows are a prominent feature of the Irish landscape. They provide an important habitat and also represent a significant store of biomass. Hedgerows are, by their nature, linear features, and difficult to quantify using conventional surveying or remote sensing techniques. CORINE does not include hedgerow vegetation as a separate class due to its 25 ha mapping. Hedgerows are therefore assimilated into the land-cover class they enclose.

Hedgerows in Ireland have not suffered the same degree of degradation and destruction as occurred in other EU countries during the second half of the 20th century. The removal of hedgerows occurred largely to facilitate the use of farm machinery, which accelerated the intensification of agriculture in Europe. Ireland has not been completely immune to this trend, however, and some consolidation of field size has occurred, particularly in the more arable and intensive dairy regions of the country, and average field size has increased. *The Badger and Habitat Survey* (1995) estimated that a total of 327,258 km of hedgerows exist in Ireland, covering approximately 1.5% of the land. For comparison, this is a similar land area as is under broadleaf forest in Ireland. As such, hedgerows might represent an important omission from the total carbon stock in living biomass.

As a habitat, hedgerows are under threat. As a carbon store, hedgerows are ignored. Although hedgerows do not achieve the same living biomass carbon density as forests, the tree and shrub species typical of hedgerows do suggest a significant capacity for carbon sequestration, if suitably maintained.

Another threat to hedgerows is rural construction. It is also estimated that some 30 m of hedgerow are lost with every ‘one-off’ housing development to meet regulatory requirements for safe road access from dwellings.

Webb (1988) estimated that 1.5% of Irish land cover was hedgerow, and that the area of hedgerow had decreased by 16% in the period since the previous national survey in 1938. It is uncertain whether this trend continued, and in recent years government schemes such as REPS have created a financial incentive to maintain and protect hedgerows. *The Badger and Habitat Survey* (1995) published by the Irish Wildlife Trust estimated the national length of hedgerow at 327,258 km. Hedgerows exist in various states of repair and development, and are a significant biomass store, including mature trees and dense brush. The Irish Wildlife Trust contends that the overall area of hedgerow is similar to that covered by mature broadleaf forest. Hedgerows are a linear landscape feature, and as such are difficult to represent in thematic land-cover maps. They are seldom the dominant cover feature, yet may be a significant carbon store in a given landscape. The majority of hedgerows were established in the 18th and 19th centuries and can therefore be considered mature systems, with limited potential for additional carbon sequestration. However, the removal of hedgerows does represent a possible loss of carbon to the atmosphere. Activity data on the repair, maintenance and removal of hedges are scarce. Assuming hedgerow removal continued at the same pace as was recorded in the period 1938–1985, then approximately 0.34% of national hedgerow is lost per annum. This corresponds to an estimated 370 ha of hedgerow per year. It has been suggested that hedgerow destruction peaked in the mid-1980s, and has declined significantly in recent years, particularly in response to REPS requirements to maintain hedges. However, anecdotal evidence suggests a more complex situation, with Dúchas complaining that some farmers set out to remove hedges prior to joining REPS in order to avoid the requirement and cost of hedge maintenance.

Assuming mature hedgerows to contain half the typical biomass of forest stands, then the carbon loss is approximately 20 t C/ha. Therefore an estimate of the hedgerow converted to other land-use loss in biomass carbon is 7,400 t C/year. This is not a trivial amount of carbon within the LULUCF sector and is of the same order as the biomass loss due to settlements.

However, further research is required before hedgerows can be included in the LULUCF estimates. Many of the assumptions used to estimate the carbon loss are speculative. There is uncertainty as to what extent CORINE, the FIPS and the upcoming NFS include hedgerows in their accounting of forest areas. As CORINE is used to estimate the amount of forest converted to settlement, the hedgerow removal for construction may already be accounted for. Hedgerow removal for agricultural purposes has not been accounted for.

Appendix D Estimate of the Area of Peat Exposed Due to Non-Commercial Extraction of Peat

According to expert opinion in Bord na Móna, approximately 1 million tonnes of peat are extracted by the non-commercial sector per annum. On average the peat depth is between 3 and 3.5 m. An average area of 4 m^2 is required to extract 1 t of peat. Therefore it can be seen that 400 ha of peat must be exploited each year (Table D1). As the biomass is returned to the cover-over of the exposed surface after the peat is extracted, the exposed area of peat is constant, and comprises those areas left exposed in preparation for next year's harvest.

Table D1. Estimation of exposed peat area due to hand cutting of turf.

Private hand-cut turbary for domestic turf (energy)	1,000,000 t
Depth of cut	3 m
Area required for 1 t	4 m^2
Volume	12 m^3
Density	83.33333 kg/m^3
Area required to extract domestic turf	4,000,000 m^2
	400 ha

Appendix E Industrial Method of Peat Exploitation

Drainage

Prior to exploitation, peatlands consist of a deep layer of dead organic material, saturated with water, usually rainwater. The decay processes are suppressed in the anaerobic conditions that prevail in the wetlands matrix. The wetlands need to be drained prior to the extraction of peat for two reasons. The wet bog is too unstable for machinery and the peat is too wet for useful application.

Drainage channels are cut, and where necessary the water is actively pumped from the channels to improve drainage. It is important to note that as soon as drainage commences the peatland area drained is effectively lost as a living bogland ecosystem. With the lowering of the water table, the aerobic zone within the peatland grows, and decomposition of the organic material of the peat accelerates, with the release of CO_2 into the atmosphere. It may be some years before the drained areas are progressed to the next stage of exploitation. However, in the meantime, for as long as the water table is lowered below the level of the living biomass material of the bog, the peat will continue to release carbon into the atmosphere. It is the human intervention of constructing the drainage system that activates the peatland as a source of CO_2 under the IPCC GPG definition of anthropogenic activity.

The IPCC GPG default emission factor for drained peatlands is 1 t C/ha/year for Ireland's climate zone.

Biomass Removal

During the summer season immediately prior to commercial extraction, the remaining living biomass on the bog is removed. Tomlinson (2005) estimates wetlands living biomass at 6 t/ha dry matter. The conversion factor to carbon content is 0.5. The default methodology assumes that the carbon content of the removed biomass is released immediately to the atmosphere. In the case of Bord na Móna activities, this may be an incidence of double-counting. Private communication with Bord na Móna suggests that the material removed is in reality incorporated into fuel products, which are reported in the energy sector of the National Inventory Report. Removal of biomass is a once-off event occurring at the commencement of peat extraction. Therefore, biomass removal occurred for the majority of actively industrially exploited sites before the reporting period.

As old cutaway bogs are depleted of peat extractable by industrial means, so new peatlands are cleared of vegetation and brought into industrial production. In general, however, there has been a gradual decline in the total area of active extraction of peat over the last 20 years.

In preparation for machine extraction of peat, material is removed to level the exposed area to a high degree of uniformity. All hummocks, typical of raised bogs, are removed from the landscape, and the landscape is a level expanse of exposed peat.

Peat Extraction

The harvesting, or extraction, of peat is a seasonal activity occurring in the summertime, when the peat is sufficiently dry and stable to allow relatively heavy machinery cross over the bog. Specialised machinery is involved which traverses the exposed peatland, cutting and disturbing the top-most layer of peat to a depth of approximately 10–15 mm, in a process known as milling. The milled peat is allowed to dry on the bog for a number of days, and it is then pushed into ridges, which are later transported off the bog using a narrow gauge railway system.

Peat, below the living biomass layers, is compacted and quite dense. Even after drainage, it is difficult for air to permeate deep into the soil matrix. Therefore, despite drainage, decay remains a relatively slow process (although much accelerated compared to undrained conditions). Decay, and the associated release of carbon to the atmosphere, is greatly enhanced with the milling process, not only in the disturbed peat, but also in the new exposed top layer.

Depending on weather and adequate drying conditions, milling of the peat can occur five to ten times during the season across the same bog. Therefore, there is frequent exposure of new peat during the summer season.

The harvested peat, itself, is accounted for in the energy sector, this being the end use of the majority of peat extracted from the bogs. The LULUCF category is only concerned with GHG activity from the peat material in the field. The default emission factor is 1.1 t C/ha/year.

After Use

Eventually, the depth of peat is severely depleted, to the extent that it is no longer possible for the machinery to safely traverse and mill the peat, without the risk of striking outcrops of the underlying rock. Therefore a depleted cutaway peatland ends its industrial life with a continuous cover of peat, the depth of which follows the contours of the underlying non-peat surface.

Over the years, many alternative after uses for cutaway peatland strategies have been researched and piloted in various parts of the country. Grassland, forestry, crops, recreational and habitat waterbody and wetlands restoration have all been investigated. Local conditions, both environmental and economic, dictate the most appropriate after use.

Conversion of the exhausted peatlands to croplands for the cultivation of cranberries and similar crops was found to be economically unviable.

Conversion to grassland, for both grazing and silage, has proved more successful, provided the drainage channels are maintained. Although peat is not an optimum growing medium for grass, with careful nutrient management, the grass can be made to flourish. Peat lacks mechanical strength, therefore grazing must be at a low intensity. If active drainage (pumping) is required to maintain the water table below the surface level, then the economic cost of grassland becomes unsustainable.

Similarly, forestry has been a relatively successful after use in certain areas. As with grassland, peat is not an optimum growing medium. The parent material of many Irish wetlands is not bedrock, but glacial till and gravel. This provides better structural foundations for forestry, provided that the depth of the peat remaining is not too great. Again, adequate drainage of the site is required, and if additional water-table management is required, beyond basic gravity-drainage channel maintenance, then the long-term viability of forestry as an economic after use is not certain.

Also, conversion of peatland to forestry, and to a lesser extent grassland, has received some criticism from environmentalists who argue for the restoration of the wetlands and against the continued disturbance of the peat which leads to further anthropogenic GHG emissions. In response to these criticisms, and also a decline in the potential economic returns from both agriculture and forestry, wetlands restoration and waterbody habitat and recreational pilot schemes have been investigated.

Where extraction of peat was only possible with active pumping of water to lower the water table, it is a straightforward process to establish a waterbody by ceasing pumping activity. Gradually the water table will rise, eventually submerging the peat surface, and creating a shallow lake. The pilot schemes have shown the natural generation of fen-type habitat within a number of years. These locations tend to be supported by river and groundwater (minerotrophic), rather than exclusively by rainwater that is more typical of Irish raised bogs. The wetlands are restored to a fen, rather than to bogland.

Figure E1 shows an estimate of the area of peatlands that has been restored to wetlands following cessation of industrial exploitation of peatlands. It is assumed that private industry has followed the example of Bord na Móna in this restoration activity.

The restoration of raised and blanket bogland is more challenging. In the preparation of the peatland for industrial exploitation, the natural hummocks and hollow features of the landscape are destroyed. These features are very slow to develop on the bog, and so restoration to a 'pristine' state that reflects natural bog development is essentially impossible. However, it is possible to encourage the repopulation of the landscape with wetland plant and animal species. The sites most suitable for bog restoration are those that did not require active pumping systems to maintain a low water table; the construction of a network of simple gravity drainage channels was sufficient to draw off enough water to keep the upper layers of the peat dry and stable enough for peat extraction. Unfortunately, these drainage channels will continue to be effective at keeping the water table low, and if the area is simply abandoned, the wetlands restoration will be determined by the slow processes that gradually block and fill in the drainage channels. In the meantime, a scrub-type vegetation will dominate the abandoned landscape, including grasses, hazel and alder. Depending on local conditions, the abandoned cutaway will probably be dominantly rain-fed, with poor nutrient availability.

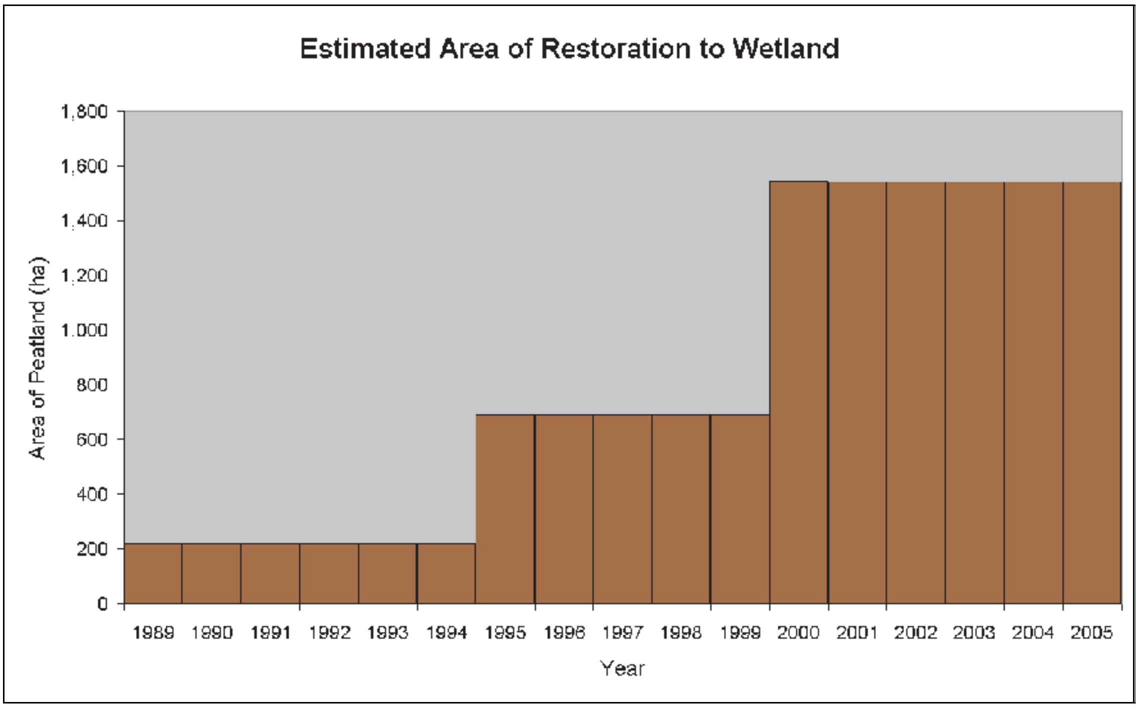

Figure E1. Time series of peatland areas restored to wetlands: 1989–2005.

The process of restoration to the more typical wetlands vegetation might be accelerated by deliberate blocking and refilling of the drainage channels.

Bord na Móna reports very promising results from its restoration pilot schemes, with unanticipated rapid regeneration of typical flora and fauna within a few years.