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Carbon emissions and removals from Irish peatlands: present trends and future mitigation measures

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In the Republic of Ireland, peatlands cover an estimated 20% of the land area and have been widely utilised over the centuries for energy production, agriculture, forestry and horticultural production. Current estimates suggest that only a small proportion of Irish peatlands are in a natural condition, and that the remainder are either moderately or severely damaged. In this paper, we reviewed carbon (C) studies for the major peatland land uses in Ireland and have estimated that at the national level, emissions from Irish peatlands and related activities (e.g. combustion, horticulture) are around 3 Mt C each year to the atmosphere. However, large uncertainties are associated with this value (1.3–4.7 Mt C yr^{-1}) due to a paucity of field studies for some peatland land uses (particularly cutover peatlands). Mitigation measures to reduce national emissions from peatlands could include: (1) a stronger enforcement approach to protect and enhance the C store in natural peatlands, (2) the rewetting / restoration of degraded peatlands to reduce emissions and create suitable conditions for C sequestration and (3) the use of alternative non-peat sources for energy production and horticulture use.

Keywords: carbon; climate change; mitigation; peat; Irish peatlands

Introduction

In the Republic of Ireland (hereafter referred to as Ireland), peatlands are a familiar part of the national landscape. Peat soils cover an estimated 20% of the land area (Connolly and Holden 2009), provide habitats for rare species, such as the red grouse (*Lagopus lagopus*) (Bracken *et al*. 2008), offer cultural, spiritual and aesthetic benefits (Feehan *et al*. 2008) and are a store for an estimated 1–1.5 billion tonnes of carbon (C) (Tomlinson 2005, Eaton *et al*. 2008, Renou-Wilson *et al*. 2011).

Current estimates suggest that *c*. 15% of Irish peatlands are in a natural state (Douglas *et al*. 2008), i.e. undrained with a very low level of degradation. These include most of the peatlands that have statutory protection as either Natural Heritage Areas (NHAs) or as Special Areas of Conservation (SACs), as well as peatlands that are not currently protected but are deemed worthy of conservation. While a core of designated sites (NATURA 2000 network) has been established, there is still a need to improve the poor conservation status in many of these peatlands (NPWS 2008) and restoring these sites is a legal requirement under the Habitats Directive as well as a first step towards the

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sustainable management of this natural resource (Renou-Wilson *et al*. 2011). The remainder of Irish peatlands (~85%) has been converted to agriculture, forested or utilised for their fuel resource. These land use changes have produced peatlands that are either moderately damaged, for example, where traditional hand cutting of the peat has been carried out, to severely damaged (industrial peatlands, small-scale mechanised turf cutting, agriculture, forestry etc.). Post-industrial peatlands (i.e. cutaways) may also undergo further land use changes driven by both commercial and ecological requirements (Renou *et al*. 2006). In general, a land use change involves the drainage of the peatland and a subsequent shift away from the characteristic peat-forming vegetation communities. As such, these land use changes are likely to have a major impact on greenhouse gas (GHG) cycling at the site, landscape and national level.

Natural peatlands play a major role in regulating the global climate by actively removing carbon dioxide (CO_2) from the atmosphere and storing C within the peat (Frolking and Roulet 2007, Dise 2009). Central to this process is the position of the water table, which when maintained at, or close to the surface of the peatland, produces conditions in which the decomposition of the plant detritus occurs very slowly (Dise 2009). Over long periods of time, this organic matter (and the C contained within) is accumulated and stored within the peatland. As a consequence of the anoxic conditions within the peat, some of the organic matter is broken down under a series of microbial-driven reactions that produces methane (CH_4) (Kettunen *et al*. 1999), a GHG with a global warming potential (GWP) 25 times that of CO_2 (IPCC 2007). Fluxes of nitrous oxide (N_2O), an even more potent GHG, generally negligible in natural peatlands may become significant during periods of drought and during the subsequent rise in water table levels within the peatland, especially in nutrient rich sites (Goldberg *et al*. 2010). The export of C from the peatland may also take place in fluvial forms, such as dissolved organic carbon (DOC) (Billet *et al*. 2004, Dinsmore *et al*. 2010), a high proportion of which is processed and converted off-site to CO_2 (Cole *et al*. 2007). Other minor fluvial components include particulate organic carbon (POC), dissolved inorganic carbon (DIC) and dissolved CO_2 (Worrall *et al*. 2009). In Ireland, it has been predicted that climate change may result in a severe diminution of the areal extent of peatlands by 2075 and with it, the C store contained within (Jones *et al*. 2006).

Currently, Annex 1 Parties to the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol are obligated to prepare annual National Inventory Reports (NIR), detailing GHG emissions and removals from six different sectors: (1) Energy, (2) Industrial processes, (3) Solvents and other product use, (4) Agriculture, (5) Land use, Land Use Change and Forestry (LULUCF), and (6) Waste. Emissions refer to the movement of GHGs to the atmosphere (all sectors) and removals refer to the movement of GHGs from the atmosphere to the biosphere (LULUCF). In light of likely accounting changes in the next Kyoto Protocol commitment period (2013–2017), which will permit the inclusion of rewetted peatlands and organic soils and their associated GHG fluxes under a new activity called ‘rewetting and drainage’ (UNFCCC 2012), there is a clear need to (1) quantify C emissions/removals from all peatland land use categories (LUCs, e.g. agriculture, forestry, peat extraction etc.), (2) identify information gaps and (3) determine suitable mitigation measures. Currently, C fluxes from natural peatlands are not reported in the NIR as the fluxes are not considered to be anthropogenic in origin, i.e. the lands are not managed (O’Brien 2007). However, emissions associated with peat combustion are reported under the Energy sector. In addition, emissions from the peat extraction fields are reported under LULUCF (Wetlands: Category 5.D), using, in Ireland’s case, Tier 1 default emission factors

(EFs). The Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidelines (GPG) identifies three levels or tiers of complexity that can be used in making GHG emissions calculations. Tier 1 is the default value derived from peer reviewed international research, uses basic activity data and has a large associated uncertainty. Tiers 2 and 3 use country specific data, are more detailed in the level of activity data reported (e.g. areas, vegetation) and have a much lower level of uncertainty associated with them. Emissions associated with grassland on organic soils, also reported under LULUCF (Category 5.C), are currently calculated by Ireland using default EFs (Duffy *et al*. 2013). However, the forested peatlands LUC (post-1990 planting) are reported at the Tier 2 level using country specific EFs and activity data.

The objectives of this paper are to: (1) review the impact of current land uses on C dynamics in Irish peatlands and identify information gaps, (2) provide an estimate of the annual C balance of peatlands at the national level, and (3) discuss mitigation measures to address emissions at the peatland site level as well as at national level.

C dynamics and land use change in Irish peatlands

Natural peatlands

Peatlands in Ireland are generally divided into areas of (1) blanket peat bogs, which are found in the wetter western parts of the country (lowland Atlantic blanket bogs) and in areas above 150 m above sea level (montane blanket bogs), (2) raised bogs, which are concentrated in the Midlands, (3) smaller areas of fens, and (4) cutaway / cutover peatlands (Hammond 1981, Fossitt 2000, Renou *et al*. 2006). Most Irish peatlands are ‘humanised’ landscapes, which have evolved, or in some cases originated, in close association with land use systems. It is highly likely that all Irish peatlands have either been grazed or have been used in some way by humans. Natural peatlands refer to peatlands that are hydrologically and ecologically intact, i.e. in which the eco-hydrology has not been visibly affected by human activity in the recent past and, therefore, includes some ‘active’ or ‘peat-forming’ areas or is deemed capable of regenerating as such a habitat. Only 1945 ha of raised bog are currently qualified as a peat-forming habitat (active) amongst the protected sites (Fernandez Valverde *et al*. 2005) and less than a fifth of the original blanket bog area is deemed to be in a natural condition (NPWS 2007).

Historically, much of the scientific research in Irish peatlands has focused on documenting the floristic (Doyle 1997, Cooper *et al*. 2001, Farrell 2001, Foss *et al*. 2001, Sottocornola *et al*. 2008) and faunal (Feehan *et al*. 2008, Renou-Wilson *et al*. 2011) composition of the various peatland types, as well as detailed investigation of the hydrological functions (Schouten 2002, Kuczyńska 2008). However, while other countries have intensely investigated C cycling in peatlands (e.g. Lapveteläinen *et al*. 2007, Billet *et al*. 2010, Maljanen *et al*. 2010), Irish peatlands remain somewhat poorly studied.

The range in mean annual flux rates (g C m^{-2} yr^{-1}) from the major peatland LUCs in Ireland is presented in Table 1. GHG studies in peatlands typically use either static chambers or eddy covariance (EC) techniques. The chamber method involves the measurement of fluxes at high spatial resolution and is widely employed in conditions where the vegetation is either low or absent. In contrast, EC towers operate at lower spatial resolutions but are suitable for sites where the biomass is vertically high (e.g. treed peatlands). For a more detailed description of methodologies see Alm *et al*. (2007). Natural peatlands are the most studied LUC in Ireland. However, the bulk of published flux values for Ireland originate from the same sole Atlantic blanket bog in Co. Kerry

Table 1. Carbon flux studies (g C m^{-2} yr^{-1}) from the major peatland land use categories in Ireland.

Location and site description	Duration (months)	CO_2–C (g C m^{-2} yr^{-1})	CH_4–C (g C m^{-2} yr^{-1})	DOC (g C m^{-2} yr^{-1})	References
Natural					
Glencar, Co. Kerry. Atlantic blanket bog: Intact condition with very light sheep grazing	12	−56 to −66	2.5–9.8	ND	Laine *et al*. (2006, 2007)
	60	−16.5 to −96.5	ND	ND	Sottocornola & Kiely (2010)
	72	−12.5 to −84	3.6–4.6	11.9–16.5	Koehler *et al*. (2011)
Clara, Co. Offaly. Raised bog. Relatively intact centre	12	−53 to 94	12.8	ND	Wilson (2008)
Slieve Blooms, Co. Laois. Intact montane blanket bog	12	17–92	2.0	ND	Renou-Wilson *et al*. (2011)
Afforested					
Cloosh, Co. Galway. Afforested Atlantic blanket bog. Sitka spruce, pine	12	1.4–2.6	ND	ND	Byrne and Farrell (2005)
Lullymore, Co. Kildare. Afforested industrial cutaway. Sitka spruce	24	−122 to −128	ND	ND	Byrne *et al*. (2007a)
Industrial cutaways					
Turraun, Co. Offaly. Nutrient rich peat.					
Areas of bare peat	24	190–308	−0.05	ND	Wilson *et al*. (2007, 2009)
Rewetted area.	24	163–760	2.4–29.1	ND	Wilson *et al*. (2007, 2009)
Scrub (birch/willow)	24	494–556	ND	ND	Byrne *et al*. (2007b)
Bellacorick, Co. Mayo Nutrient poor peat. Rewetted	36	82 to −588	0.1–12.3	ND	Wilson *et al*. (2013)
Cutover peatlands					
Clara, Co. Offaly. Raised bog. Drained margins. Mechanised peat cutting.	12	122–441	0	ND	Wilson (2008)
Slieve Blooms, Co. Laois. Montane blanket bog. Hand cut. Abandoned.	12	55–170	0.88	ND	Renou-Wilson *et al*. (2011)

Positive flux values indicate either carbon emissions to the atmosphere (CO_2 and CH_4) or export from the peatland to water bodies (DOC). Negative values indicate carbon removal from the atmosphere by the peatland. ND denotes not determined.

(Laine *et al*. 2006, Laine *et al*. 2007, Sottocornola and Kiely 2010, Koehler *et al*. 2011). These studies clearly show the wide range in inter-annual variation in C fluxes at a single site and highlight the necessity of long-term monitoring to develop robust baseline data-sets. For example, Koehler *et al*. (2011) calculated six years of C balances (CO_2-C, CH_4-C and DOC) and showed that the peatland was a net C sink in four of the years and a net C source in the other two. DOC losses from the peatland were particularly significant and in two of the years of the study were higher than CO_2-C uptake. Short-term studies in other natural peatlands have reported small annual losses of CO_2 and CH_4. For example, Wilson (2008) estimated that Clara raised bog was a source of around 30 g CO_2-C m^{-2} over a 12-month period but noted that there was considerable variation in gas fluxes within the peatland with the wetter areas (which benefited from restoration) acting as a small CO_2 sink (Table 1). An annual net loss of CO_2-C was also reported for a montane blanket bog in Co. Laois (Renou-Wilson *et al*. 2011).

Forested peatlands

In an effort to increase the forest cover in Ireland, considerable areas of peatlands were afforested by the State over the second half of the twentieth century. These new peatland forests changed the Irish landscape introducing coniferous species, such as Sitka spruce (*Picea sitchensis* (Bong.) Carr.), lodgepole pine (*Pinus contorta* Dougl.) and Norway spruce (*Picea abies* (L.) Karst.) into previously treeless, windswept expanses. Despite the fact that these state peatland forests were considered mostly unprofitable (Farrell and Boyle 1990), private afforestation followed on due to state grants to support the costs of afforestation. At the turn of the twenty-first century, the area of afforested peatlands is estimated at 293,000 ha (Forest Service 2007) or 43% of the forest estate. The majority of planting was carried out on lowland and montane blanket bogs, where despite continued financial incentives from the Irish government and the European Union (EU), the economic viability remains marginal (Renou and Farrell 2005). While the remainder of the Irish forests (i.e. planted on mineral soils) have been shown to be a significant C sink (O'Donnell *et al*. 2013), the impact of afforestation on C cycling in these peatland ecosystems is complex and studies are currently ongoing at a number of sites around the country (http://www.ucd.ie/carbifor/chronosequence.html). Research has shown that cultivation of the peatland prior to tree planting is likely to result in severe damage to the peatland vegetation (Charman 2002, Anderson 2010) and the installation of drainage ditches will lead to a general lowering of the water table (Byrne and Farrell 1997, Lewis *et al*. 2012) and increased emissions of CO_2 (Byrne *et al*. 2000, Byrne *et al*. 2001). The drainage of peat soils promotes a release of CO_2 due to oxidation of the organic matter in the aerobic layer, although this loss of C can be partially or entirely offset by (1) greater inputs of organic matter, i.e. in the vegetation, tree layer and root biomass (Hargreaves *et al*. 2003, Byrne and Farrell 2005), and (2) a decrease in CH_4 fluxes (Fowler *et al*. 1995). At present, there exist many types of forested peatlands throughout the country depending on the pre-afforestation conditions of the peatland sites (drained, grazed, cutover etc.). From the current international literature, the majority of studies have reported that forested peatlands are likely to be net CO_2 sinks (e.g. Lohila *et al*. 2011, Ojanen *et al*. 2013, Meyer *et al*. 2013), although soil CO_2 emissions may be considerable in some cases (Minkkinen *et al*. 2002, Hargreaves *et al*. 2003, Byrne and Farrell 2005). A meta-analysis conducted by Worrall *et al*. (2011) concluded that in 71% of the studies that they reviewed, peatland afforestation led to an improvement in the C sink function. The strength of this sink will vary as a result of various factors: namely tree stand development and site characteristics (e.g. nutrient status of the peat) as well as management practices, all of which will have an impact on the various C pools in the system. However, it is important that the potential C benefits from peatland afforestation do not displace the requirements to protect designated habitats and species under the relevant EU Directives.

Agriculture

The utilisation of Irish peatlands for agricultural activities extends back many centuries (Feehan *et al*. 2008). Reclamation of peatlands for agriculture was accelerated during the eighteenth and nineteenth centuries as a result of population pressures and has accounted for a considerable loss in the peatland cover in Ireland over the years. The reclamation and drainage of organic soils was intensified in the twentieth century as a result of several Acts and Schemes, including the 1945 Arterial Drainage Act, the Farm Improvement Programme and the Programme for Western Development. Agricultural activity on peat soils is largely confined to grassland production and the grazing of cattle or sheep. This may result in large emissions of GHGs due to the drainage of the peat soils (CO_2), enteric fermentation associated with grazing ruminants (CH_4) and N_2O emissions from fertiliser applications (Byrne *et al*. 2004).

In the 1980s and 1990s, the primary threat to the C store in Irish peatlands from agriculture was from overgrazing of the more vulnerable upland peatlands. However, the impact on C dynamics from overgrazing has not been quantified in Ireland. High livestock stocking rates, in this case encouraged by financial incentives under the EU's Common Agriculture Policy (CAP), may have had three major impacts on C dynamics in peatlands. Firstly, the combined effects of intensive grazing and drainage remove much of the peatland vegetation cover. This results in a reduction in the C sequestering capacity of the peatland (i.e. less photosynthesis is likely to take place), as well as a decrease in the amount of organic matter input available for peat formation (Garnett *et al*. 2000). Secondly, trampling by the sheep may cause compaction of the peat (Clay and Worrall 2013) and result in a disturbance of hydrological functioning, with a corresponding deleterious impact on C cycling (Garnett *et al*. 2000). Thirdly, high stocking rates have been linked to severe soil erosion. Large losses of DOC have been associated with erosion in the Pennines in the UK (Evans *et al*. 2006). However, Worrall *et al*. (2007) monitoring DOC levels in a blanket bog in the UK reported no significant difference between ungrazed areas and those maintained at low stocking rates. In recent years, the threat from overgrazing has receded somewhat with the introduction of agri-environmental schemes and the decoupling of CAP subsidies. However, eroded bare tracks of blanket bog are likely to sustain continued degradation if no restorative action is undertaken and it has been suggested that, in terms of the C balance, this impact is actually irreversible, even with active re-vegetation (Evans and Lindsay 2010).

The annual CO_2 emissions from peatlands and organic soils under grassland is currently evaluated in Ireland using the Tier 1 reporting method (IPCC 2006) which involves multiplying the national activity data by the default EF of 0.25 tonnes C ha^{-1} yr^{-1} (Duffy *et al*. 2013). Studies to date on drained organic soils in Ireland suggest that the default factor is likely to be very conservative and that emissions of C are likely to be considerably higher (Wilson *et al*. 2007, Wilson 2008, Renou-Wilson *et al*. 2012).

Peat extraction

In Ireland, around 100,000 ha of peatlands are utilised for peat extraction (Fitzgerald 2006). The majority of this area (80%) is owned by the semi-state body Bord na Móna, which extracts around four million tonnes of peat annually for energy production and horticultural products (Bord na Móna 2010). The peatlands used are predominantly the raised bogs in the Midlands, although some of the lowland blanket bogs have also been exploited (Renou *et al*. 2006). In order to facilitate industrial extraction of the peat, drainage ditches are installed to lower the water table and reduce the moisture content of the peat from approximately 95% to 80% (Bord na Móna. www.bnm.ie). The installation of drainage ditches increases the depth of the oxic zone in the upper layers of the peatland (Waddington *et al*. 2001) resulting in increased losses of CO_2.

After a number of years, the acrotelm layer at the surface (where C is actively sequestered) is removed in order to facilitate the removal of the more highly decomposed peat within the catotelm and the surface of the peat is levelled. The removal of the acrotelm layer has a number of important effects on the system. It disrupts hydrological processes, adding to the changes brought about by drainage, i.e. peat shrinkage, compression, reduced hydraulic conductivity and pore size etc. (Price and Schlotzhauer 1999, Schlotzhauer and Price 1999, Price *et al*. 2003). However, more importantly it removes the C sequestering capability of the system (Waddington and Price 2000). Peat extraction transforms the peatland into a considerable source of CO_2 (Rodhe and Svensson 1995, Sundh *et al*. 2000) but may result in a small uptake of CH_4 from the bare peat surface (Wilson *et al*. 2009) although drainage ditches may remain a significant CH_4 source (Minkkinen and Laine 2006) particulary if vegetation is established. Additional emissions of CO_2 occur from the stockpiled peat (Nykänen *et al*. 1996) and from the combustion of the peat in power stations (Lappi and Byrne 2005).

Domestic cutting of peat (i.e. cutover peatlands) has been a notable feature of the Irish landscape. In recent times, hand cutting has largely been superseded by the use of tractor-mounted extractors. Two methods have been generally employed. In the first, the peat is extruded (following drainage of the peat) onto the surface of the peatland from narrow openings made in the peat by a chain cutter (Foss *et al*. 2001). This practice has a number of deleterious effects on the peatland; (1) the vegetation is damaged as the tractor is repeatedly driven across the surface of the peatland in the process of harvesting the peat (Wheeler and Shaw 1995), (2) the acrotelm and catotelm are compressed by the passing of the tractor over the surface (Cooper *et al*. 2001) resulting in a reduction of pore size and an increase in bulk density, and (3) it creates deep crevices within the peat that function indirectly as drainage ditches. As the peat dries out, the crevices are further deepened and cracking of the peat is accentuated leading to a severe drop in the water table. The second method of extraction involves the block cutting of the peat at the margins of the peatland. The extracted peat is placed into a tractor-mounted hopper and the peat is extruded on the surface.

When a peatland is damaged through small-scale peat extraction there are likely to be a number of critical differences to that of adjacent natural peatlands (Wilson 2008). Firstly, removal of the peat results in severe disruption of hydrological functioning with the peatland with the consequence that water table levels drop significantly and remain at a permanently low level (Wilson 2008). Deep fissures within the peat caused by previous peat extraction methods exacerbate the draining effect and lead to an increased oxygen content within the peat. Secondly, the effect of a deeper oxic zone caused by lower water table levels leads to higher rates of decomposition (Glatzel *et al*. 2004) and increased emissions of CO_2. Thirdly, as with CO_2 exchange, the deep oxic zone is an important controller of CH_4 fluxes insofar as it determines the depth of peat available to the methanotrophic bacteria that oxidise CH_4.

A default EF of 0.25 tonnes C ha^{-1} yr^{-1} for drained organic soils (IPCC 2006) is currently used by Irish inventory compilers and probably represents a considerable under-estimation of emissions given that measured fluxes from industrial peat extraction areas in Ireland (Table 1) are within the range (0.55 to 11.2 tonnes C ha^{-1} yr^{-1}) reported by studies elsewhere (see review in Wilson *et al*. 2012). Studies are currently in progress to develop more accurate EFs that would allow for Tier 2 inventory reporting for drained organic soils (Renou-Wilson 2011). For cutover peatlands (sites impacted by domestic peat extraction), very few C studies have been carried out to date. Wilson (2008) reported that emissions of CO_2 were six to seven times higher from the margins of the peatland, where mechanised peat extraction had lowered the water table considerably, than from the relatively intact central area of the peatland. Similarly, Renou-Wilson *et al*. (2011) observed much higher CO_2 emissions from a degraded montane blanket bog than from an adjacent natural site.

Fire

Fire is an increasing global threat to the ecosystem services provided by peatlands, not least their C store (Turetsky *et al*. 2004, Robinson 2009). Increased human activity, in addition to the impact of climate change, are making peatlands more susceptible to fires (Flannigan *et al*. 2009, IPCC 2010). In tropical peatlands, the threat posed by fire to the C store is of major regional and global importance (Maltby and Immirzi 1993, Page *et al*. 2002). The Indonesian peat and forest fires of 1997 are estimated to have released between 0.81 and 2.57 Gt of C into the atmosphere, equivalent to 13–41% of the world's annual C emissions from fossil fuels (Page *et al*. 2002). In Ireland, the threat from fire is considerably less, although periodically peatlands have undergone burning from carelessness by the public, to facilitate the extraction of the peat, and to increase the population of grouse. The number of fires associated with wind farms on peatlands is also likely to become an increasing phenomenon (Malone and O'Connell 2009). The loss of C from fire in Ireland has not been quantified. However, work in North America and Finland has suggested that between 2.1 and 3.2 kg C m^{-2} could be released during a single fire event (Pitkänen *et al*. 1999, Turetsky and Wieder 2001, Turetsky *et al*. 2002, Benscoter and Wieder 2003) and that the burned peatland is likely to be a net C source for some time afterwards as a result of the loss of the vegetation cover (Turetsky *et al*. 2002). However, Clay *et al*. (2010) reported lower CO_2 emissions from a burned peatland than from their control site and suggested that this was due to higher rates of photosynthesis and lower rates of respiration by the new vegetation stand.

Industrial cutaway peatlands (post-peat extraction)

In recent years, the restoration of the environmental conditions (i.e. water table, vegetation recolonisation) required to promote the return of the C sink function in peatlands damaged by peat extraction has received much interest globally (Komulainen *et al*. 1998, Komulainen *et al*. 1999, Tuittila *et al*. 1999, Tuittila *et al*. 2000, Waddington *et al*. 2003, Bortoluzzi *et al*. 2006, Yli-Petäys *et al*. 2007). However, it has been slower to develop in Ireland where the alkaline peat substrate remaining after the cessation of industrial peat extraction is not suitable for recolonisation by ombrotrophic bog species, such as *Sphagna* (Farrell and Doyle 2003, Renou *et al*. 2006). Recent work by Wilson *et al*. (2012, 2013) at a rehabilitated acidic industrial cutaway peatland in Co. Mayo has highlighted the potential for C sequestration in damaged peatlands where appropriate land management decisions have resulted in (1) high water table levels throughout the year, and (2) subsequently high rates of C uptake (Table 1). Beyond that particular study, the main focus in Ireland has been to quantify C dynamics in a range of new land use options that have developed with the ending of industrial peat extraction. The results from the various studies have suggested that there are considerable differences in the ability of the new ecosystems to sequester C (Table 1). For example, Byrne *et al*. (2007a) reported that a 19-year-old Sitka spruce afforested cutaway peatland was a sink for CO_2-C but that a naturally regenerated birch/willow woodland of the same age was a large source (Byrne *et al*. 2007b). The discrepancy in values was attributable to differences in stand productivity and site management (Wilson and Farrell 2007) with much larger amounts of C sequestered by the Sitka spruce stand. In both peatlands, the authors reported large losses of soil CO_2 from the residual peat, as have other studies in Finland (Mäkiranta *et al*. 2007) and Sweden (Tagesson and Lindroth 2007). To date, there is no information as to how C cycling is likely to change over the lifetime of an afforested or naturally regenerated stand on cutaway peatland.

Are Irish peatlands a net C sink or source?

Derivation of EFs

The IPCC 2006 GPG primarily stratify default EFs in organic soils by climate zone. More recent work by the IPCC to derive EFs for both drained and rewetted organic soils has also found that flux rates between boreal and temperate regions are significantly different (IPCC 2013). Given the paucity of published peatland C studies in Ireland and in order to provide a reasonable estimation of annual C emissions / removals (tonnes C yr^{-1}) for each peatland LUC in Ireland, we also utilised data from peatland C studies located within the temperate climate zone. Data were further stratified by LUC (Table 2). Where possible, the reported values for CO_2-C, CH_4-C, DOC and biomass removal (agriculture) were extracted from peer reviewed publications and entered into an Excel database. For multi-year studies from the same site (e.g. Koehler *et al*. 2011), annual flux estimates were averaged over the years of the study to reduce uncertainty due to inter-annual variation in annual flux values. The average C balance of each LUC was calculated and an EF (tonnes C m^{-2} ha^{-1}) was derived. Confidence intervals (95%) were calculated for each LUC. Emissions / removals for each LUC were then estimated by multiplying the EF by the appropriate area value for each LUC. Insufficient data was available to derive an EF for the afforested peatlands LUC. Instead, emissions / removals for this LUC were adapted from the NIR (Duffy *et al*. 2013). Further details of our approach are described below in the forested peatland section.

Natural peatlands

The land area covered by peatlands deemed worthy of conservation has been estimated at 269,267 ha by Malone and O’Connell (2009). This value is likely to be an overestimation of the area of natural peatlands in Ireland given that it includes peatland areas that have been degraded to some extent but are still considered of conservation value. Similarly, it is likely that much of the UK peatland data used here is from peatlands that have been damaged to some extent (Worrall *et al*. 2011). However, for the purposes of this exercise

Table 2. Carbon flux rates (tonnes C ha^{-1} yr^{-1}), area (ha), emissions/removals (tonnes C yr^{-1}) and uncertainty range (95% Confidence Intervals) from the main peatland LUCs in Ireland.

Land use category	Flux rates (tonnes C ha^{-1} yr^{-1})	Area (ha)	Emissions (tonnes C yr^{-1})	Uncertainty range (tonnes C yr^{-1})
Natural peatlands	−0.27 (±0.44)[a]	269,267	−72,702	−191,180 to 45,775
Afforested	N/A	293,000	−668,000	−774,880 to −561,120
Grassland	4.72 (±1.58)[b]	295,000	1,392,400	926,300–1,858,500
Industrial peat extraction				
Production fields	2.1 (±0.67)[c]	70,000	147,000	100,100–193,900
Undrained	−0.27 (±0.44)[d]	2819	−761	−2001 to 479
Rewetted cutaway: nutrient poor	−0.37 (±0.92)[e]	11,136	−4,120	−14,365 to 6125
Rewetted cutaway: nutrient rich	1.75 (±1.53)[f]	10,320	17,544	1,754–33,334
Cutover	1.1 (±0.86)[g]	612,377	673,315	146,970–1,200,259
Total			1,484,975	192,698–2,777,252

Positive flux and emission/removal values indicate carbon emissions to the atmosphere. Negative values indicate carbon removal from the atmosphere by the peatland. N/A denotes that flux rates were not derived from published flux studies (see main text).

Notes: Literature used: [a,d]Hargreaves *et al.* (2003), Worrall *et al.* (2003), Billet *et al.* (2004), Wilson (2008), Worrall *et al.* (2009), Dinsmore *et al.* (2009, 2010), Drewer *et al.* (2010), Renou-Wilson *et al.* (2011), Koehler *et al.* (2011); [b]Byrne *et al.* (2004), Nieveen *et al.* (2005), Lloyd (2006), Jacobs *et al.* (2007), Veenendaal *et al.* (2007), Schils *et al.* (2008), Couwenberg (2011), Elsgaard *et al.* (2012), Petersen *et al.* (2012), Schrier-Uijl *et al.* (2013); [c]Waddington *et al.* (2002), Cleary *et al.* (2005), Wilson *et al.* (2007, 2009), Couwenberg (2011), Järveoja *et al.* (2012), Salm *et al.* (2012); [e]Drosler (2005), Bortoluzzi *et al.* (2006), Strack and Zuback (2013), Wilson *et al.* (2013); [f]Hendricks *et al.* (2007), Wilson *et al.* (2007, 2009), Herbst *et al.* (2013); [g]Wilson (2008), Rowson *et al.* (2010), Evans and Lindsay (2010), Renou-Wilson *et al.* (2011).

it represents the best data available and is used accordingly to estimate C emissions / removals at the national level. The literature sources used in the derivation of the EF can be found in Table 2. We estimate that natural peatlands in Ireland are likely to be a net sink of around 72,702 tonnes C yr^{-1} with a wide uncertainty range of 191,180 (sink) to 45,775 (source) tonnes C yr^{-1} (Table 2). The high uncertainty around this estimate reflects the variation in peatland types, vegetation communities, hydrological regimes and local climate factors.

Forested peatlands

Given the dearth of published annual C gas balances from afforested peatlands in the temperate climate zone, we were unable to derive an EF for this LUC. Instead, we adapted the values reported in the most recent NIR (Duffy *et al.* 2013). Organic soils which encompass both peat soils and organo-mineral soils (e.g. peaty podsols) are estimated by Duffy *et al.* (2013) to account for 60% of the forested land area pre-1990 (Forest Land remaining Forest Land category) and 57% of the forested land area in post-1990 areas (Land converted to Forest Land). This gives a value of around 437,000 ha of forestry on organic soils, (includes afforested cutaway peatlands), of which around 293,000 are peat soils (Forest Service 2007). Total removals by the forestry sector (estimated using Tier 2 methodology) from mineral and organic soils are estimated to be 1,147,253 tonnes CO_2-C for 2011. By applying the same proportions used in the area calculations, we estimate that forests on organic soils are a net C sink of 668,000 tonnes C yr^{-1} (Table 2). There is a 16% uncertainty associated with the estimate (Duffy *et al*. 2013), producing an uncertainty range of 561,120 (sink) to 774,880 (sink) tonnes C yr^{-1}.

Agriculture

In Ireland, the majority of peat soils reclaimed for agriculture have been used for grassland with a negligible area used for cropland. It is estimated that organic soils under grassland cover approximately 295,000 ha (CRF Table 5.C, National Inventory Report 2007–2009). For this exercise, we have reviewed a sufficient number of studies to derive an EF of 4.72 tonnes C ha^{-1} yr^{-1} (includes C exported as biomass). At the national level, this equates to estimated annual emissions of around 1.4 Mt C yr^{-1}, with an uncertainty range of 0.9–1.85 Mt C yr^{-1}. This figure excludes C exports in the form of milk and meat and C imports in the form of cattle concentrate feeds and slurry. The high uncertainty associated with this LUC primarily results from variations in management practices between study sites and differences in grass composition and productivity.

Peat extraction

Malone and O'Connell (2009) have estimated that around 612,377 ha (340,721 ha of blanket bogs and 271,692 ha of raised bogs) of Irish peatlands have been affected by domestic peat extraction (i.e. cutover peatlands). We have derived an estimate of 1.1 tonnes C ha^{-1}, which if extrapolated to the national level would equate to 673, 315 tonnes C yr^{-1}. Given the very large areas associated with this LUC and the paucity of C studies, it is not surprising that the uncertainty range for the cutover LUC is very large (see Table 2).

In Ireland, industrial peat extraction is carried out by Bord na Móna, six medium-sized companies (Bulrush, Clover, Erin, Harte, Klasmann-Deilmanna and Westland) and a range of smaller entities (Malone and O'Connell 2009). The lands owned by Bord na Móna are divided into active production fields, reserve areas, undrained peatlands, access roads, landfills, work areas, as well as peatlands that have come out of production (i.e. cutaway peatlands) (Farrell 2007). In total, approximately 70,000 ha of peatlands are in active production and we estimate that they are a source of 147,000 tonnes C yr^{-1} (Table 2). Emissions from stockpiles are not included.

Annual C gas fluxes from industrial cutaway peatlands are relatively minor as a consequence of the small land areas involved. In terms of emissions / removals, afforested cutaways are amalgamated within the larger afforested LUC (as reported by Duffy *et al*. 2013). Due to the absence of data, we were not able to derive an estimate for naturally regenerated scrub. Rewetted nutrient poor industrial cutaways are estimated to be a C sink of 4120 tonnes C yr^{-1} with an uncertainty range of 6125 (source) to 14,365 (sink) tonnes C yr^{-1} and rewetted nutrient rich industrial cutaways are estimated to be a C source of 17,544 tonnes C yr^{-1} with a range of 1.754 (source) to 33,334 (source) tonnes C yr^{-1}. Much of the variation within these two LUC can be attributed to differences in microsite composition following rewetting (e.g. bare peat, vegetation communities), hydrological conditions and time since rewetting.

Indirect losses of C occur when the extracted peat undergoes combustion at the three peat-fired power stations in the Republic of Ireland (736,362 tonnes C yr^{-1}) and through domestic combustion of sod peat and briquettes (281,720 tonnes C yr^{-1}) (Table 3). These emissions are reported under the Energy sector in Ireland's NIR each year. An uncertainty

Table 3. Annual C emissions and uncertainty range (tonnes C yr^{-1}) from peat related energy production and horticultural extraction in Ireland.

Activity	tonnes C yr^{-1}	Uncertainty range
Electricity generation	736,362	699,544–773,180[a]
Residential	281,720	225,376–338,064[b]
Horticulture	535,080	229,320–840,840[c]
Total	1,553,162	1,154,240–1,952,084

Positive values indicate C emissions to the atmosphere. Data for electricity generation and residential emissions adapted from Duffy *et al*. (2013).
[a]±5% uncertainty value.
[b]±20% uncertainty value (see Duffy *et al*. 2013).
[c]Uncertainty range based on using two bulk density values (0.18 and 0.66 tonnes/m^3) to represent non-compressed and compressed peat, respectively. See main text for full description.

estimate of 5% and 20%, respectively, is reported by Duffy *et al*. 2013. This results in an uncertainty range of 699,544–773,180 tonnes C per year for the power stations and 225,376–338,064 for domestic combustion. However, emissions associated with horticulture are not currently accounted for within the NIR and so an estimate of the emissions is provided here (Table 3). The annual production of peat extracted for horticultural use has been estimated at 2.6 million cubic metres (Clarke 2006). By assuming (1) bulk density values of 0.18 and 0.66 tonnes/m^3 for non-compressed and highly compressed moss peat, respectively (Ayalew *et al.* 2007), (2) a C content of 49% (Tomlinson 2010) and (3) that all the C in the peat is emitted in the extraction year (IPCC 2006) this would result in average emissions of 535,080 tonnes C yr^{-1}. This would equate to an EF of 206 kg C m^{-3}, considerably higher than the 55 kg C m^{-3} reported by the UK (Barthelmes *et al*. 2009). However, it is likely that the value for annual emissions presented here is an underestimation, given that the production of horticultural peat is increasing in Ireland (Joosten and Clarke 2002).

In total, compiling all on-site and off-site figures, Irish peatlands are likely to be a net source of around 3 Mt C yr^{-1} (11 Mt CO_2 yr^{-1}) to the atmosphere with an uncertainty range of (1.3–4.7 Mt C yr^{-1}). This is on a par with the emissions from the Transport sector (11.16 Mt CO_2 yr^{-1}) (Duffy *et al*. 2013).

Uncertainties and information gaps

There are large uncertainties associated with up-scaling flux values measured in often spatially limited studies to the wider national level (Black 2007). The uncertainties in the estimated emissions / removals values reported in this paper result from a combination of factors.

(1) There is an inherent variation in the flux values used in the derivation of the EF for each LUC. This may result from different measurement methodologies between each study (e.g. EC or static chambers), the data modelling approach, differences in site characteristics (e.g. nutrient poor / rich), variations in the vegetation composition both between *and* within study sites and, in the case of afforestation, variation in age structure and yield class.

(2) There is a general lack of data for most of the peatland LUCs. Ireland is not alone in this regard as other studies have also highlighted the scarcity of detailed information on peatlands (e.g. Joosten 2009, Maljanen *et al*. 2010, Frolking

et al. 2011, Worrall *et al*. 2011). While natural peatlands in the temperate climate zone have been reasonably well studied, large information gaps exist for the other LUCs. Currently, research is underway in Ireland to provide improved EFs for both drained and rewetted organic soils (Renou-Wilson 2011) and afforested peatlands (Tobin *et al*. in preparation). Furthermore, with the exception of the natural peatland LUC for which DOC values were available, the values reported here are mainly for C gas fluxes only, and as recent studies have demonstrated fluvial C loss from a peatland is a highly significant component of the total C balance (Billet *et al*. 2010, Koehler *et al*. 2011, Strack and Zuback 2013). Research on drained and rewetted organic soils in Ireland will soon provide not only values for DOC but also POC and pCO_2 from these LUCs (Renou-Wilson 2011). Given that CH_4 emissions from drainage ditches are likely to be highly significant (Minkkinen and Laine 2006, Strack and Zuback 2013) there is an obvious need to (1) quantify the level of CH_4 emissions from ditches and (2) provide high resolution spatial data to allow up-scaling. N_2O emissions have not been addressed in this paper as published annual EFs are scarce. However, given that N_2O is a potent GHG and that studies elsewhere have documented significant episodic emissions, particularly in grassland LUCs (e.g. Kasimir Klemedtsson *et al*. 2009), there is an obvious requirement to fill this information gap.

(3) The activity data (e.g. area statistics) used in this study originates from a range of sources and is subject to a level of uncertainty, some of which can be reasonably well quantified (e.g. afforestation). Sources of uncertainty in regard to activity data may include the omission or duplication of areas, especially if the data has been gathered from a variety of sources, the omission of historical data and insufficient information on the land use history and current land use. When information regarding activity data is gathered from a variety of sources, cross-checks should be made to ensure complete and consistent representation of land management practices and areas (IPCC 2006). New research, currently funded by the Environmental Protection Agency (EPA), aims to provide a more precise estimation for the area of organic soils, particularly those under grassland (EPA 2013).

Mitigation measures

The results presented in this paper are an estimate of emissions / removals from the main peatland LUCs in Ireland and associated off-site emissions (energy combustion and horticulture). Clearly, the aim in seeking to reduce national peatland emissions is to conserve those LUCs that are currently sequestering C and provide mitigation measures to reduce the C emissions from the other LUCs and associated off-site activities.

Preservation and conservation

Almost 30 years after the mobilisation of national interest in peatlands through the founding of the Irish Peatland Conservation Council, there is still no peatland policy in Ireland and peatland protection has been restricted to the designation of a small number of Natura 2000 sites, which has afforded them little protection from ongoing turf cutting. Ireland has been found in breach of the EIA Directive and the Habitats Directive on several occasions, not least in relation to peatlands (European Court of Justice ruling case

C215/06). As natural peatlands in Ireland have been estimated here to be small net C sinks, there is a clear need to enforce their protection, regardless of the political sensitivity of such actions. Ireland is obligated under the Habitats Directive to not only maintain, but also *restore to favourable conservation status*, the protected habitats listed in Annex 1, including all natural peatland types and also degraded raised bogs. This is of critical importance as it has already been demonstrated that Ireland has lost 25% of its area of 'active raised' bog habitat between the period 1995 and 2005 (Fernandez Valverde *et al*. 2005), with such a loss likely to have accelerated due to the continued degradation through turf cutting during that period.

Rewetting and restoration

Rewetting of damaged peatlands has been considered as a 'low hanging fruit, and among the most cost-effective options for mitigating climate change' (Achim Steiner, UN Under-Secretary General and Executive Director UN Environment Programme (UNEP). This was officially recognised in 2010 when rewetting of drained peatlands and organic soils as a climate mitigation action was fully recognised by the UNFCCC. A 2013 Wetlands supplement to the 2006 IPCC GPG for Inventory Compilers (IPCC 2006) is currently in development and will enable the quantification of changes in the C stock of rewetted peatlands, hitherto disregarded due to the lack of scientific data. In addition, the potential for rewetted peatlands to be used in voluntary C offset programmes has received an impetus with the development of Peatland Rewetting and Conservation (PRC) / Wetland Restoration and Conservation (WRC) modules by the Verified Carbon Standard (VCS) programme (http://v-c-s.org/). Large rewetting and restoration projects have already begun around the world (Parish *et al*. 2008, Joosten 2012). In Belarus, the reduction of GHG emissions and enhancement of biodiversity values have been successfully demonstrated through the restoration and sustainable management of large areas of currently degraded peatlands. As a consequence, a scheme for the sale of C credits to secure further peatland rewetting activities and, therefore, future biodiversity protection and enhancement has now been developed (Tanneberger and Wichtmann 2011). A similar approach (MoorFutures 2.0) has been established in Germany to finance rewetting of degraded fens (http://www.moorfutures.de/en). In Ireland, rewetting and restoration of different peatland LUCs has been led by various stakeholders (Coillte, Bord na Móna, National Parks and Wildlife Service) but remains largely piecemeal and mostly experimental. The establishment of a Strategy for Irish Peatlands, to be published by the Peatland Council (www.peatlandscouncil.ie, 2013), would help further develop this management option in combination with the recent EPA-funded national monitoring network of rewetted and restored organic soils for climate and biodiversity benefits (www.ucd.ie/neros and Renou-Wilson 2013).

Forested peatlands

The results from this study would indicate that afforested peatlands are a C sink at the national level. However, their economic viability and aesthetic qualities may be questionable and C dynamics beyond the first rotation cycle is largely unknown. Some areas have been restored under the EU LIFE project (Delaney 2008). This involved clear felling of the trees (the mature trees removed off-site and the younger trees left on-site), drain blocking, rewetting and the removal of invasive tree species, with the overall objective of raising the conservation value of the site. Losses of C through deforestation are inevitable and would fall under Article 3.3 of the Kyoto Protocol. Furthermore, reforestation is compulsory under the Forestry Act of 1946, unless a derogation is issued by the Minister for Agriculture, Food and the Marine.

Peatlands used for agriculture

As discussed earlier, overgrazing has a number of deleterious impacts on the peatland. However, this is not to say that grazing *per se* is unacceptable, as grazing at low stocking levels have been shown to have minimal impact on the C balance in some temperate peatlands (e.g. Worrall *et al*. 2007, Dinsmore *et al*. 2009, Drewer *et al*. 2010, Skiba *et al*. 2013). Furthermore, the rewetting of marginal agricultural lands may offer the potential to reduce CO_2 emissions/sequester CO_2 but may also result in an increase in CH_4 emissions, depending on the water table level (Renou-Wilson *et al*. 2012). The potential benefits of creating a wet soil environment have been recognised by Denmark, for example, who currently use an EF of −0.5 tonnes C ha^{-1} yr^{-1} for 'wet grassland' (i.e. water table position 0–30 cm) and an EF of 3.0 tonnes C ha^{-1} yr^{-1} for drained agricultural organic soils (i.e. water table deeper than 30 cm). Rewetting of agricultural lands would require a considerable change in mindset from individual farmers, as blocking of drains and rewetting fields is somewhat counterintuitive. Rewetting in this instance would have to be combined with financial instruments to compensate the farmers for loss of earnings from reduced stocking rates. Furthermore, concerns as to flood risk to neighbouring land holdings may be an issue in some cases.

Rewetting cutaway and cutover peatlands

Successful rewetting of the industrial (cutaway) and domestic (cutover) peat extraction lands could lead to significant reductions in C emissions (i.e. avoided losses) and may create suitable conditions for net C sequestration. Work by Wilson *et al*. (2012) in an industrial cutaway peatland demonstrated that the action of rewetting alone (i.e. drain blocking) reduced C emissions by 87% and in turn led to widespread vegetation recolonisation within a very short time frame. Bord na Móna have estimated that up to 40,000 ha wetlands could be created from industrial peatlands. However, for a variety of reasons (e.g. topography, peat type) not all cutaway and cutover peatlands may be successfully rewetted. Furthermore, given that climate change models have predicted that the Midlands are likely to experience higher summer temperatures and lower rainfall in the decades ahead (Sweeney *et al*. 2008), the challenge of maintaining suitable hydrological conditions within some of these cutaways will be problematic.

Alternative energy sources

Since the 1950s, industrial peat extraction from raised bogs in the Midlands and blanket bogs in the west of Ireland provided an indigenous source of energy for electricity generation, which in turn provided an economic stimulus in those disadvantaged rural areas. Reducing the magnitude of emissions would necessitate Ireland firstly realigning its energy policy away from the C intensive fuel that is peat, recognising the finite nature of this natural resource, acknowledging that the current portfolio of commercial use of peat is not sustainable and finding alternative energy sources. However, it is important to note here that Ireland currently imports around 90% of its energy requirements and peat (energy generation and domestic) contributes 5.5% of the total energy requirements

(Howley *et al*. 2012). From a climate point of view, any substitution of peat would be beneficial given that CO_2 emissions associated with the combustion of peat briquettes (98.9 tonnes CO_2/TJ), sod peat (104 tonnes CO_2/TJ) and milled peat (116.7 tonnes CO_2/TJ) are much higher than those associated with natural gas (57.1 tonnes CO_2/TJ) and coal (94.6 tonnes CO_2/TJ) (Sustainable Energy Authority of Ireland 2012). Bord na Móna are currently committed to a 30% co-firing target with biomass by 2016 in Edenderry power station (Bord na Móna 2011), although this may be restricted by the availability of indigenous biomass and may necessitate the importation of biomass from abroad (Shier 2008). Furthermore, they are actively involved in expanding their wind power generation capacity with planning permission secured for a 350 MW wind farm in Mayo (Bord na Móna 2011) and a new wind farm in Co. Offaly on industrial cutaway bogs. Reducing emissions from domestic peat extraction is likely to be more problematic given relatively high oil prices, a depressed domestic economy and the politically sensitive nature of turf cutting in Ireland.

Alternative horticulture products

The issue of peat in horticulture has received considerable attention in recent years primarily due to the perceived destruction of natural habitats (Alexander *et al*. 2008, Boon and Verhagen 2008). The results presented here in this paper would suggest that C emissions from peat compost are highly significant. Emissions can be mitigated to large extent by the use of either peat-free compost or by dilution of the peat content with non-peat biomass / organic matter. In the UK, the general public have been receptive to these new products driven by a strong public awareness campaign. Bord na Móna has also joined in similar initiatives and has developed its own waste composting centre to develop peat-diluted and peat-free growing media. In the long-term, this should have a positive impact in reducing the overall requirements for peat. However, the changeover to alternative growing media has been much slower in the professional horticulture market and requires further technological advances (Renou-Wilson *et al*. 2011). The absence of regulation in Ireland in respect to peat use has meant that the British horticultural industry has begun increasing its imports of peat, much of these from Ireland (Joosten and Clarke 2002).

Conclusions

For a number of reasons, not all emissions / removals from peatland LUCs are currently reported in the NIR, while in some cases emissions / removals are reported using default EFs that may be too low. The estimate of peatland-related C gas emissions reported in this paper for the Republic of Ireland shows that, at a national level, peatlands are likely to be a large net annual C source. However, this paper has also highlighted the large uncertainty in this estimate due to a paucity of published studies and the associated gaps in knowledge. That the majority of Irish peatlands have been degraded suggests that the natural C sequestration function has been lost and, therefore, presents a major challenge for Ireland. This paper has concluded that one of Ireland's low-C opportunities lies with the implementation of a peatland policy promoting mitigation measures that will primarily seek to reduce C emissions from the various peatland LUCs at the national level. This can be achieved through (1) stronger conservation actions, (2) rewetting / restoration of degraded peatlands where possible and (3) alternative sources for energy generation and horticultural use. Decisions regarding the management of this vast natural resource need immediate attention and should be sufficiently informed with regard to the condition of all peatland LUCs, as well as the consequences of inappropriate actions.

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