IEA Bioenergy Task 38 – Case Study

Greenhouse Gas Budgets of Peat Use for Energy in Ireland

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Summary

Peatlands in Ireland have accumulated large amounts of carbon from the atmosphere since the last ice age. In their natural state, peatlands act as sinks of carbon dioxide, but sources of methane. In Ireland, four million tonnes of peat is extracted annually to produce 6% of the total primary energy requirement. The combustion of peat generates greenhouse gas emissions, mainly carbon dioxide. These emissions accounted for 5.7% of the total greenhouse gas emissions in Ireland in 2001. In addition to the emissions from peat combustion, other stages of peat use contribute to the total greenhouse gas balance of peat use for energy. Peat production fields emit large amounts of carbon dioxide, but methane losses are much less significant compared to undrained peatland. Construction of lifecycle analysis of peat use for energy in Ireland would provide information of the contribution of peat use for energy to the national greenhouse gas balance as well as the possibility to compare the greenhouse gas balance of the peat lifecycle to that of other energy sources. Such an analysis requires more information than is presently available on greenhouse gas fluxes of undisturbed raised bogs, peat production fields and industrial cutaway peatlands under different after-use management regimes.

Peat is the least carbon efficient fossil fuel producing more CO_2 emissions per energy unit than oil, natural gas or coal. The net emissions from a peat burning power plant could be reduced significantly by replacing part of the peat with biomass fuels. Potential sources of biomass are forest residues, purpose grown energy crops, sawmill residues and recovered wood. The price of generating electricity by biomass is currently not competitive compared to the price of fossil fuels in Ireland. However, the energy markets may be subject to change in the future as a result of the effects of carbon taxation and the emission trading scheme increasing the attractiveness of biomass as an energy source.

Replacing part of the peat with recovered wood in the Edenderry power plant, which is the first of the new peat burning fluidised bed plants in Ireland, could potentially reduce the greenhouse gas emissions from the combustion process by 8-36%. However, due to information gaps, the greenhouse gas balances of the whole lifecycles of co-firing recovered wood with peat and sole combustion of peat can only be compared qualitatively.

List of abbreviations

EF	emission factor
EPA	Environmental Protection Agency
ESB	Electricity Supply Board
GHG	greenhouse gas
GWP	global warming potential
IPCC	Intergovernmental Panel on Climate Change
LORCA	long-term apparent rate of carbon accumulation
LULC	land use and land use change
MC	moisture content
TPER	total primary energy requirement
TFC	total final consumption
UNFCCC	United Nations Framework Convention on Climate Change

Chemical compounds

CO_2	carbon dioxide
CH_4	methane
N_2O	nitrous oxide

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1. Introduction

IEA Bioenergy Task 38 – Greenhouse Gas Balances of Biomass and Bioenergy Systems analyses and integrates information on bioenergy, land use, and greenhouse-gas mitigation covering all components that constitute a biomass or bioenergy system, from biomass production to bioenergy conversion and end use. This aims to aid policy and industry decision makers in selecting mitigation strategies that optimise greenhouse gas benefits while being practical and cost effective. Countries that participate in the Task conduct case studies of the greenhouse gas mitigation potential for a range of biomass and bioenergy systems. This work is the first Irish case study for Task 38.

The primary objective of this study was to further the understanding of the carbon budgets of all stages of peat use for energy, and to identify the research necessary to enable a comprehensive assessment of the climatic impact of the whole peat energy lifecycle to be carried out. The study also aimed to assess the potential for improving the greenhouse gas profile of peat use for energy, concentrating on the potential emission reduction achieved by co-firing peat with recovered wood in the power plant operated by Edenderry Power.

2. Methodologies

Assessing the potential contribution of peat use for energy to the national greenhouse gas balance requires an understanding of the greenhouse gas balances of each component of the peat energy lifecycle. In this study, this was achieved by reviewing the available literature and research findings mainly from Nordic countries. Based on this, further research required for assessing the climatic impact of peat use for energy in Ireland was identified.

The Irish Environmental Protection Agency produces annual emission data for the National Greenhouse Gas Inventory. This data was used to analyse the emissions from peat combustion. Emission data was also obtained from the Electricity Supply Board (ESB) and Edenderry Power. The information used for the calculation of greenhouse gas fluxes from peat production fields was obtained from the Intergovernmental Panel on Climate Change Good Practice Guidance on Land Use, Land-Use Change and Forestry (IPCC 2004), the National Greenhouse Gas Inventory of Finland (Ministry of the Environment 2003) and Bord na Móna (Shier 2003).

The information used in estimating the potential emission reduction achieved with co-firing biomass with peat was obtained from a number of sources. Assessing the availability of biomass fuels was based several of Irish studies. The potential emission reduction was examined in the Edenderry power plant with hypothetical co-firing of recovered wood with peat.

3. Peatlands and Use of Peat in Ireland

Peat is a biogenic deposit which is formed under waterlogged conditions when organic matter is produced by plants and deposited at a faster rate than it is decomposed (Feehan and O'Donovan 1996). Peatlands originally covered 1 177 000 ha or 17.2% of the area of the Republic of Ireland. They are divided into three main peatland types, raised bogs, blanket bogs and fens. Fens are often nutrient-rich and relatively fertile, while bogs are acid and nutrient-deficient. Raised bogs and fens are found mainly in the central plain. Blanket bogs occur along western seaboard and mountain ranges throughout the country. Raised bogs cover 311 000 ha, blanket bogs 774 000 ha, and fens 92 000 ha of the total peatland area (Hammond 1981, Otte 2003).

Raised bogs started to form after the last ice age, about 9 000 years ago, on the low-lying calcareous midland plain. Partially decomposed plant material began to accumulate on the bottom of shallow post-glacial lakes gradually filling the entire basin. This fen stage of raised bog formation was followed by a further accumulation phase under the influence of rainwater. This led to the formation of ombrotrophic peat domes typical of undisturbed raised bogs (Otte 2003).

For centuries, peatlands in Ireland have been used for agricultural, forestry and energy purposes. Today 57% of the fens, 18% of blanket bogs and 8% of the raised bogs remain relatively intact (Foss 1998, Foss & O'Connell 1996).

Peat is mainly used for energy production in Finland and Ireland and to a lesser extent in Sweden, Russia and former republics of Soviet Union. In Ireland, peat was traditionally cut by hand to provide home heating fuel and the majority of households were dependent on peat as the only source of energy. Large-scale industrial harvesting of peat and its use in energy production started in the 1950s. The extraction of peat is concentrated on raised bogs in the midlands and blanket bogs in the west of Ireland (Feehan & O'Donovan 1996).

Bord na Móna is a state owned company and was established in 1946 to manage the peat harvesting activities. Apart from private harvesting of peat for domestic fuel, Bord na Móna is the only producer of peat for energy production in Ireland (Foss et al. 2001). Of the 1.2 million hectares of peatlands in Ireland, Bord na Móna owns 80 000 ha or 7% of the total peatland reserve. Of that area, approximately 40 000 ha is currently affected by peat harvesting and further 12 000 ha is former peat production fields under different land-uses. Bord na Móna harvests around four million tonnes of peat annually. The amount of peat harvested depends on the weather conditions in a particular year. Around three million tonnes of peat per year is used for energy production by power plants, less than half million tonnes for briquette production and one million tonnes as horticultural peat. The remaining time for peat extraction of these reserves is estimated to be 15-20 years (Bord na Móna 2002). In addition to the peat harvested by Bord na Móna, estimated 650 000 tonnes of sod peat is harvested per year by the private sector. Harvesting in milled form is the main method for extracting peat in Ireland. Machine harvested sod peat was formerly used in large-scale energy production, but today it is only used domestically and harvested from smaller peatlands unsuitable for large-scale production. On average, it takes 10 years to harvest a one metre depth of milled peat and 40-50 years to remove the whole economic peat reserve (Feehan & O'Donovan 1996).

Apart from natural gas, peat is the only significant domestic source of energy in Ireland and therefore it has an important role in the energy policy of the country. Currently peat contributes 21% of the total energy produced by native sources (Bord na Móna 2002). The peat fuel industry has been subsidised by the government because it has been seen to be important for the security and flexibility of energy supply and because of its contribution to the rural employment (Feehan 1994). Currently around 6% of the total primary energy requirement and 7.6% of the electricity used is produced by peat. The total primary energy requirement and final consumption of different energy sources is shown in Figure 3.1.

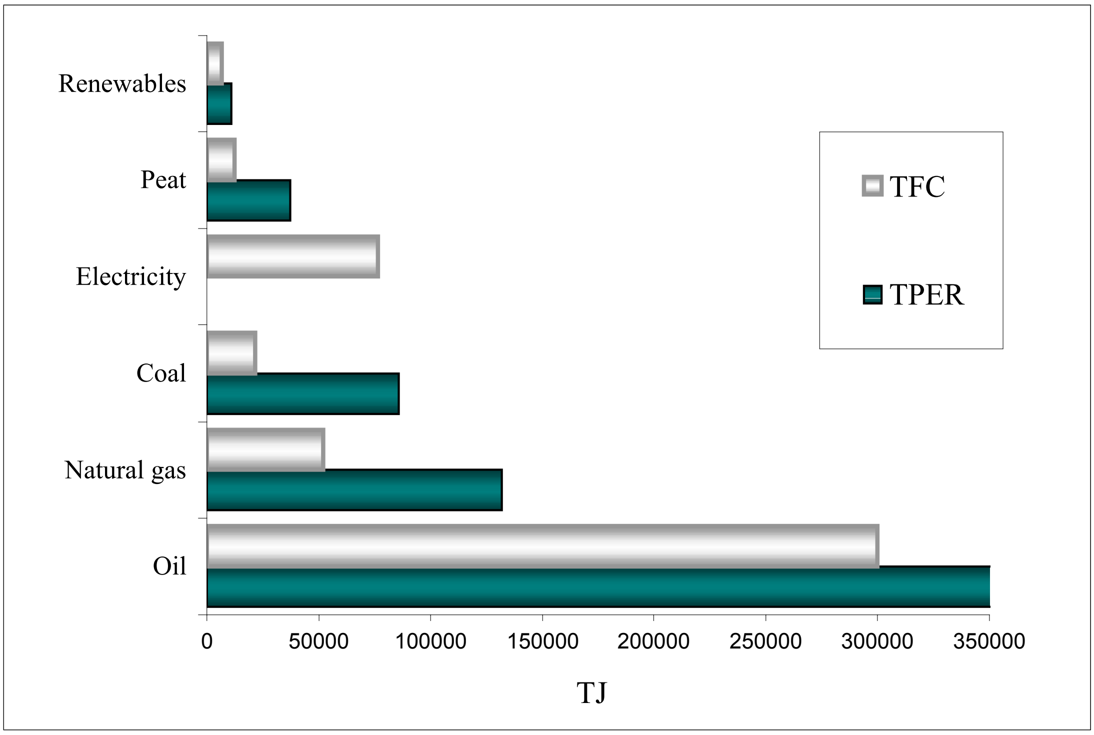

Figure 3.1. Total primary energy requirement (TPER) and total final consumption (TFC) in 2001 (McGettigan and Duffy 2003).

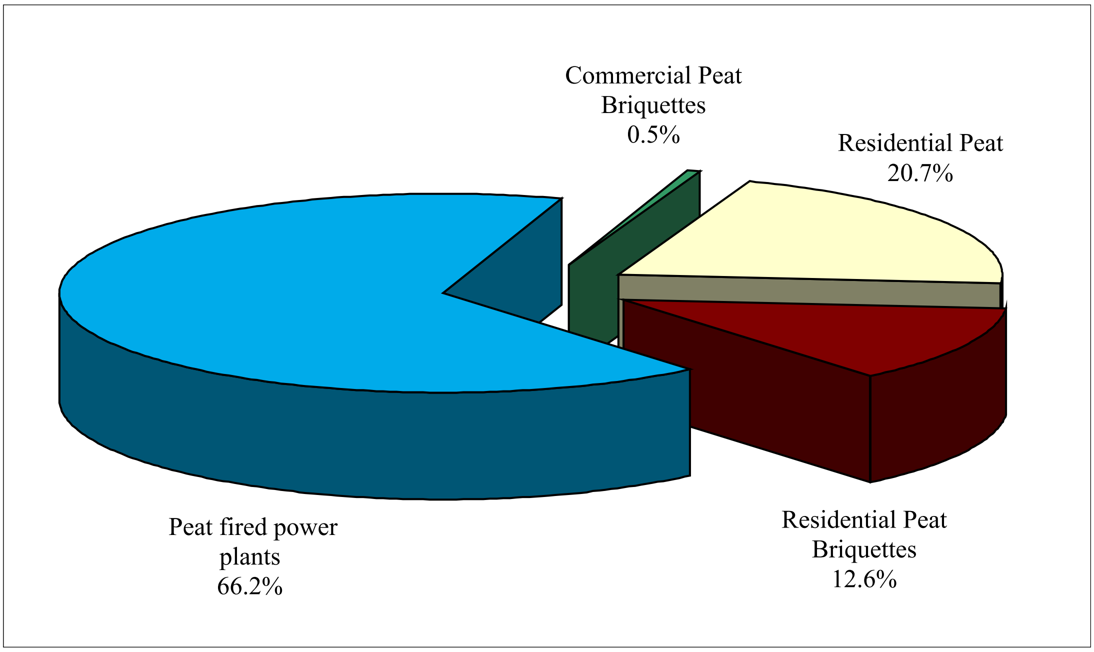

Figure 3.2. Consumption of peat energy 2001 (McGettigan & Duffy 2001).

The first sod peat burning power plant was established in Portarlington in 1950 followed by a milled peat power plant in Ferbane seven years later (Foss et al. 2001). Energy generation from peat peaked during the oil crisis in 1960s, when around 40% of total electricity production was from peat (Feehan & O'Donovan 1996). Currently, peat is combusted in four power plants producing electricity, of which three are operated by the Electricity Supply Board (ESB) and one by Edenderry Power Ltd. Their total production capacity is 295 megawatts (Table 3.1).

Table 3.1. Production capacity of peat burning power plants in Ireland (McQuade 2003).

Peat burning power plants	*Capacity (MW)*
Bellacorrick	40
Shannonbridge	125
Lanesboro	85
Edenderry	118

The importance of peat in energy production has declined in last decades. In the near future, Bellacorrick power plant will close and Shannonbridge and Lanesboro power plants will be replaced with new plants. These will use two million tonnes of peat per year giving a total production capacity of 250 MW. The new ESB power plants should be in operation in 2004/2005 and the old plants are planned to be decommissioned at the same time. The first one of the new power plants was commissioned in 2000 in Edenderry. This plant has a production capacity of 118 MW using 1 million tonnes of peat per year. Edenderry Power Ltd operates the plant, but the ESB will purchase the total capacity of the plant (McQuade 2003).

It is currently estimated that peat extraction for large-scale energy production in Ireland will cease in 15-20 years. Approximately 12 000 ha of Bord na Móna peatlands have so far become cutaway peatlands. This area is increasing every year and it is expected that more than 80 000 ha will become cutaway peatlands after the large-scale peat extraction ceases (Shier 2003). The choice of after-use of cutaway peatlands depends on number of factors including the residual peat depth, the properties of the sub-peat mineral soil, water level and drainage, climatic conditions etc. (Feehan & O'Donovan 1996). Forestry, wetland development and dryland recolonisation are the most important after-use alternatives. Other alternatives such as conversion to grassland and use as a landfill will only be used on a small area of cutaway bogs, and are therefore not discussed here in detail. Figures 3.3 and 3.4 illustrate the current and future use of Bord na Móna cutaway peatlands (Shier 2003).

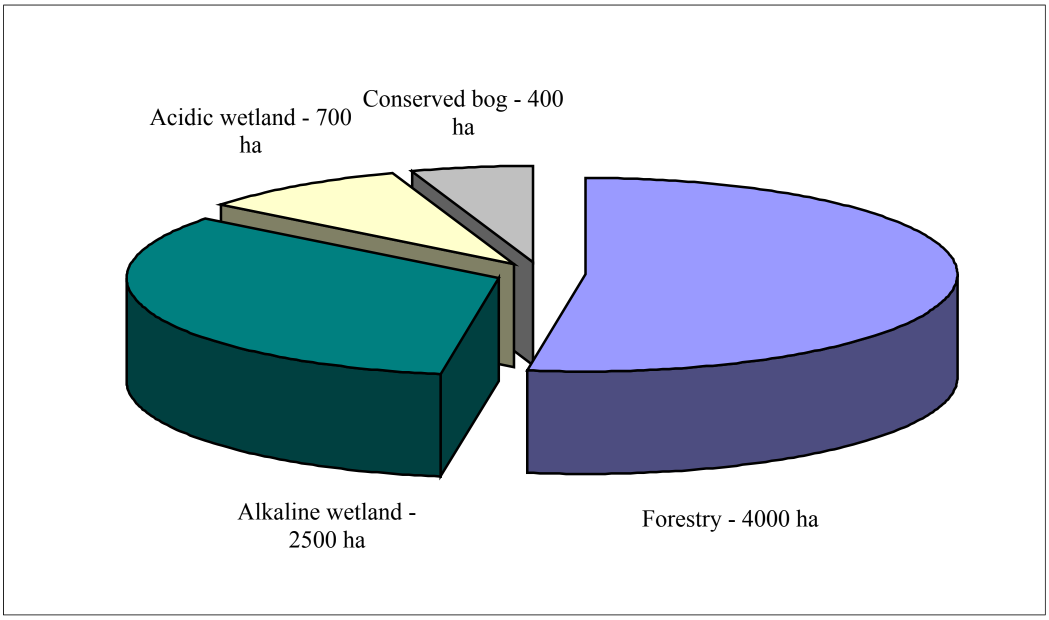

Figure 3.3. Current use of Bord na Móna cutaway bogs (Shier 2003).

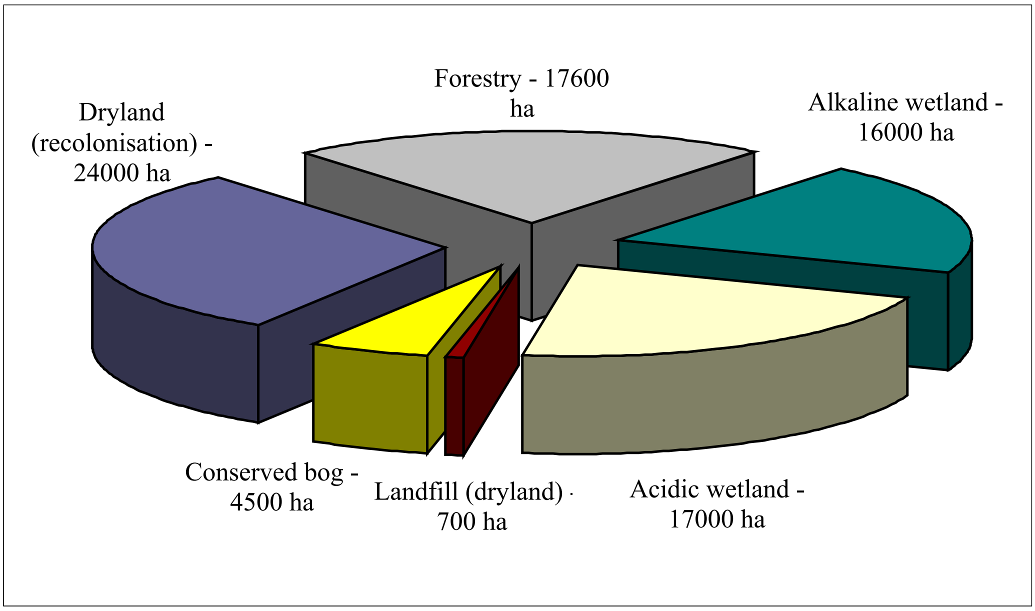

Figure 3.4. Projections for the future use of Bord na Móna cutaway bogs (Shier 2003).

Forestry is one of the most important after-use options for cutaway peatlands. Several cutaway sites have been planted with different tree species over the years. The productivity of the forests has varied significantly due to tree species and depth of peat, and problems have occurred due to frost damage, vegetation competition, nutritional problems and pest damage. Research indicates that despite the problems, forestry on cutaway peatlands has commercial potential. The BOGFOR research programme has been on-going since 1998 and aims to establish and develop a successful forest resource on the cutaway peatlands providing appropriate silvicultural options to ensure optimum forest productivity compatible with environmental imperatives. Preliminary findings are being tested and refined to be finally incorporated into a code of best forest practices for cutaway peatlands (Jones & Farrell 2000).

Another alternative is to leave cutaway peatlands to develop into natural habitats by themselves. Cutaway sites have an inherit capacity to regenerate naturally and vegetation will eventually start to grow on milled cutaway peatlands. Cutaway bogs can in time start to develop into birch, willow or pine forests (Feehan & O'Donovan 1996). However, the process is very slow since no vegetation and therefore no viable seedbank is left. Furthermore, fluctuations in the water table and harsh microclimate may restrict plant colonisation on cutaway sites (Tuittila 2000).

Many areas currently used for peat harvesting are drained by pumping. The most likely use for these areas once peat harvesting is ceased is wetland generation. This may involve work such as blocking ditches in order to stabilise or raise water levels. This will be followed by colonisation with wetland plant species and peat development can be assumed to begin (Brooks & Stoneman 1997).

4. Peat as a Source of Energy

In functioning peatland ecosystems peat is formed from litter produced by vegetation adapted to waterlogged conditions. Dead organic matter is thus deposited into long-term storage for over thousands of years. Peat has a high carbon content (approximately 50%) and in Irish climatic conditions, a high moisture content (on average 55% for milled peat). The heating value of dry peat is lower than of most fossil fuels, but higher than that of biomass on dry weight basis. The carbon dioxide emissions generated in combustion process are high. Table 4.1 shows the average emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) of different fuel combustion processes.

Table 4.1. Average greenhouse gas emissions of different fuels (Hillebrand 1993).

Fuel	*g CO_2/MJ*	*mg CH_4/MJ*	*mg N_2O/MJ*
Peat	110	4.5	2
Wood	115	40	2
Coal	93	5.5	2
Oil	77	8	2
Natural Gas	53	3	1

Table 4.1 only shows the emissions generated by the power production unit. Wood and peat appear to have the largest emissions of greenhouse gases and therefore the largest potential to contribute to global warming. However, the carbon cycles of peat and wood include the potential of peatlands and forests to sequester atmospheric carbon and therefore reduce the impact of the combustion process on climate change. Combustion of coal, oil and natural gas do not have this potential to mitigate the greenhouse gas emissions by sequestration of carbon (Hillebrand 1993).

The potential of fuel combustion to contribute to global warming can be considered in the short- or long-term. The short-term greenhouse effect of wood and peat combustion is significant. The cumulative greenhouse effect of peat and wood diminishes in the long-term as a result of carbon accumulation by peatlands and forests. For peat, taking into account the long period of time for carbon accumulation, this will take hundreds of years (assuming that the after-use practice is such that carbon accumulation occurs). In contrast, the cumulative greenhouse effect of coal, oil, and natural gas continues to grow. In the long-term, wood combustion has the smallest warming impact on the climate (Hillebrand 1993, Savolainen et al. 1994).

The debate over the classification of peat as fossil or biomass (renewable) fuel has been ongoing for several years. The process of peat development from organic matter suggests that peat might be classified as biomass fuel. However, the concept of renewable biomass fuel includes a potential to renew in the short-term. The time scale of renewing of biomass fuels is of the order of tens of years, while the renewal of peat takes thousands of years. This is still a much shorter time scale than the renewal of fossil fuels (i.e. coal, oil, natural gas), which takes millions of years. Based on this, peat is clearly different from both biomass fuels and fossil fuels.

As a result of this, peat has been classified differently by different countries and interested parties. The peat and energy industries generally promote classifying peat as non-fossil fuel, either the same category as wood and other biomass fuels or in its own category as a slowly renewable biomass fuel. This has been supported by countries where peat use for energy is significant, such as Finland and Sweden. In Sweden, peat is included in the list of fuels eligible for the green certificate with renewable energy sources such as wind power, solar power, geothermal energy and biomass. Environmental organisations have strongly opposed the classification of peat as renewable fuel, stating that the time scale for peat to renew would put it in the same category as coal, oil and natural gas. The United Nations Framework Convention on Climate Change (UNFCCC) and Intergovernmental Panel on Climate Change (IPCC) have also classified peat as fossil fuel. Peat is treated as fossil fuel in Ireland and the emissions from the peat combustion are included in the national greenhouse gas inventory. This means that peat energy producers will be subjected to emission reduction activities such as carbon taxation and emission trading scheme.

5. Climate Change and Peatlands

The greenhouse effect is a naturally occurring phenomena, which has enabled life on earth to develop, keeping the surface temperature about 30°C warmer than it otherwise would be. The earth's surface absorbs radiation from the sun, which is redistributed by the atmosphere and oceans and radiated back to space. The concentration of greenhouse gases is increasing in the atmosphere due to fossil fuel burning and changes in land-use. Increased greenhouse gas concentrations reduce the proportion of long wave energy radiation back to space and therefore warm the climate (Berdowski et al. 2001). The main greenhouse gases emitted by human activities are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFC), perfluorocarbons (PFC), and sulphur hexafluoride (SF_6) (IPCC 2001).

As stated, emissions of greenhouse gases change the radiation balance between earth and space. Radiative forcing is a measure of the influence a factor has in altering this balance and an index of the importance of the factor as a potential climate change mechanism. Negative radiative forcing has a cooling effect and positive radiative forcing a warming effect. This is usually expressed using global warming potential (GWP) which is an index which approximates the time integrated warming effect of a unit mass of a given greenhouse gas in today's atmosphere relative to that of CO_2. Each greenhouse gas has a different potential to alter the radiation balance of the earth-atmosphere system (IPCC 2001). The global warming potential of the three main greenhouse gases is shown in Table 5.1 (IPCC 2001).

Table 5.1. Global warming potential of CO_2, CH_4 and N_2O (IPCC 2001).

Gas	Lifetime (years)	Global Warming Potential for 100 Years Time Horizon (W/m^2)
CO_2	Variable	1
CH_4	12	23
N_2O	114	296

The UNFCCC was developed at the UN Conference on Environment and Development in 1992 and was the first global attempt to deal with greenhouse gas emissions. Although it did not set binding emission reduction target, parties were committed to prevent dangerous anthropogenic interference with climate system. This was followed in 1997 by the Kyoto Protocol which set legally binding emission reduction targets for developed countries. Under the Protocol, developed countries have to reduce emissions of six greenhouse gases to 5% below 1990 levels by the first commitment period of 2008-2012. The Protocol will come into force when 55 developed countries with over 55% of the total greenhouse gas emissions have ratified the Protocol. Currently, 180 countries are Parties to the UNFCCC and 120 countries representing 44.2% of the 1990 emissions have ratified the Protocol (UNFCCC 2003).

Under the Kyoto Protocol, European Union (EU) has committed to reduce greenhouse gas emissions by 8% from 1990 levels in the first commitment period, 2008-2012. The EU has distributed the emission reduction target differently between the member states taking into account the efforts needed by individual states to reach the emission reduction targets. Under this agreement, Ireland has committed to limit the emissions of greenhouse gases to 13% above 1990 levels by 2008-2012 (McGettigan & Duffy 2003).

5.1 Peatland and the Carbon Cycle

Peatlands have accumulated large amounts of carbon from the atmosphere over a long period of time and play a major role in the global carbon cycle. Peatlands can act as sinks or sources of CO_2 and CH_4. They may also be a source of N_2O. The impact of peatlands on climate change depends on the net emissions of these three gases taking into account their radiative forcing potentials. The contribution of peatlands to greenhouse gas balances depends on the environmental and geographic conditions, type and age of the peatland and land-use (Lappalainen 1996).

Peatlands are significant reservoirs of carbon. Carbon in peat in boreal and temperate regions is estimated to be around one third of the carbon stored in the worlds soils (Gorham 1991).

The carbon cycle of peat use for energy production includes fluxes of greenhouse gases from all stages of the process. These are:

- Initial stage - undisturbed peatland
- Preparation of peatland to peat extraction and extraction of peat
- Combustion
- After-use of cutaway peatland.

In pristine peatland ecosystems net primary production exceeds the rate of decay. This results formation of peat and accumulation of carbon (Lappalainen 1996). Peatland ecosystems consist of two layers, an upper aerobic layer (acrotelm), where the rate of decay of organic matter is high and the lower anaerobic layer (catotelm) with a lower rate of decay. A major part of the carbon held by the vegetation returns to the atmosphere due to plant and microbial respiration. About 5-10% of the biomass and therefore carbon is added to the peat store (Joosten & Clarke 2002). This carbon is left in the soil as decaying plant material. In the acrotelm the decaying plant material releases carbon in the form of CO_2. 80-95% of the organic matter is decomposed by aerobic bacteria in the upper part of the peatland and is released into the atmosphere as CO_2 (Crill et al. 2000).

In anaerobic conditions beneath the water table, the decay of organic matter is very slow and most of the carbon is released as CH_4. This CH_4 is formed from organic or gaseous carbon by methanogenic bacteria. CH_4 is transported through the aerobic zone of peatland where it may be oxidised and released as CO_2. The total amount of CH_4 emitted depends on the level of CH_4 produced and oxidised (Crill et al. 2000). The emissions decrease with an increasing depth of water table (Roulet et al. 1993). Emissions are also influenced by primary production, since a significant part of the emissions are derived from recently fixed organic matter (Chanton et al. 1995). High CH_4 emissions are associated with vascular, deep-rooted plants such as sedges, since these plants efficiently transport CH_4 from the anaerobic layer to the atmosphere (Armstrong 1979). Generally fens which receive groundwater and are dominated with vascular plant vegetation emit more CH_4 than bogs dominated with *Spaghnum* moss (Lappalainen 1996).

Carbon accumulation rates varies between different peatland types, age of the peatland and geographic location. The variation can be high. In the long-term, bogs accumulate more carbon than fens. Peatlands in southern latitudes also accumulate more carbon than northern ones (Lappalainen 1996).

Extraction of peat disturbs the natural cycle of carbon in peatlands. Lowering of the water table due to drainage increases the depth of aerobic peat and therefore CO_2 emissions. CH_4 emissions generally cease following drainage. The removal of plant cover in areas converted to peat production also cancel the CO_2 sequestration (Minkkinen & Laine 2001).

Areas associated with peat production fields can also contribute to the total greenhouse gas balance of peat extraction. Ditches and boundaries along the peat production fields are usually vegetated and have different carbon balances than the production fields, generally emitting more CH_4 than the production fields. Stockpiles and ridges where peat is stored before transportation to the power production units act as sources of CO_2 (Crill et al. 2000).

Although all stages of peatland use contribute to the greenhouse gas balance of peat use for energy, the combustion of peat is the biggest contributor to greenhouse gas emissions of the whole lifecycle of peat use for energy. The majority of the carbon that has been accumulated as peat is released during the combustion process in the form of CO_2. The amount of CO_2 emissions depends on the heating value, moisture content and carbon content of peat. Emissions of CO_2 from combustion are significant, but CH_4 and N_2O emissions are small (Crill et al. 2000, Hillebrand 1993).

After the peat extraction has ended, the cutaway peatlands can act as sinks or sources of greenhouse gases. This depends on the chosen after-use practice.

The carbon balances of forestry have not been extensively studied on cutaway peatlands in Ireland. Overall, forests on cutaway peatlands are likely to be net sinks of carbon, but this can be uncertain since the carbon balance of peatland soils under forestry is not fully quantified. Forestry activities in peatlands contribute to the greenhouse gas budget in two ways. The actual forest stands will accumulate carbon in their biomass, therefore acting as sinks of CO_2. Due to the drainage and evapotranspiration the peat soil will act as a source of CO_2. Carbon will also be stored in the soil due to litter deposited on the soil surface. CH_4 and N_2O fluxes will most likely be small (Crill et al. 2000).

The creation of wetland will likely change the cutaway peatland to a source of CH_4, but sink of CO_2. The fluxes of CO_2 and CH_4 will vary significantly between rewetted sites depending on the degree and type of vegetation cover, peat and water properties and climatic variables such as light and temperature (Crill et al. 2000).

5.2 Current Research of Greenhouse Gas Fluxes of Peatlands

The carbon fluxes of undisturbed peatland can vary significantly depending on the climate, age and type of peatland. Greenhouse gas fluxes of different peatland types have been studied mostly in the Nordic countries, USA and Canada. The fluxes of CH_4 are most widely studied, while fewer studies have been conducted of CO_2 and especially N_2O fluxes. The majority of the studies have concentrated on the different types of undisturbed peatlands. Finland is currently the only country that is aiming to provide comprehensive information on greenhouse gas fluxes of all types of peatlands and land uses. Research is currently underway with the objective of developing dynamic emission factors (EFs) for different kinds of peatland and land-use types. This will help to identify the peat production chain that makes the smallest contribution to climate change. Within next few years, a significant amount of new information of the greenhouse gas fluxes will become available as a result of this research.

The long-term carbon accumulation of undisturbed peatland has been studied in several countries. The long-term apparent rate of carbon accumulation (LORCA) throughout the holocene can be calculated when profile of bulk density to the whole depth of peatland and the basal date have been estimated. LORCA values of 185 kg C ha^{-1} yr^{-1} (684 kg CO_2 ha^{-1} yr^{-1}) in Finland, 200 kg ha^{-1} yr^{-1} (740 kg CO_2 ha^{-1} yr^{-1}) in the Russian Karelia, 194 kg ha^{-1} yr^{-1} (718 kg CO_2 ha^{-1} yr^{-1}) in western Canada and 172 kg ha^{-1} yr^{-1} (636 kg CO_2 ha^{-1} yr^{-1}) in western Siberia have been estimated (Joosten & Clarke 2002). However, we have no knowledge on how well the accumulation rates, averaged over the whole post-glacial development of peatlands coincide with the present carbon sequestration in these systems. Table 5.2.1 shows average CO_2 sequestration and emissions of CH_4 and N_2O in undisturbed peatlands in Finland and Sweden where the research has been most extensive.

Table 5.2.1. Average sequestration of CO_2 and emissions of CH_4 and N_2O in undisturbed peatlands in Finland and Sweden.

	CO_2 (kg ha^{-1} yr^{-1})	CH_4 (kg ha^{-1} yr^{-1})	N_2O (kg ha^{-1} yr^{-1})
Finland (Crill et al. 2000)	-750	135	0.05
Sweden (Uppenberg et al. 2001)	-580	210	-

No comprehensive studies on carbon accumulation or fluxes of greenhouse gases in Irish raised bogs have been carried out. In Northern Ireland, peatlands cover around 15% of the land area, but hold 42% of the total carbon stored in soils (Cruickshank et al. 1998). Comprehensive information has not been published in the Republic of Ireland, but based on the study in Northern Ireland and the significant area that peatlands cover in the Republic, it can be assumed that peatlands hold major share of the carbon stored in Irish soils. Irish blanket bogs are estimated to accumulate carbon in rate of 320 kg C ha^{-1} yr^{-1} (1184 kg CO_2 ha^{-1} yr^{-1}) (Moore et al. 1975). Accumulation by raised bogs is generally higher and therefore Irish raised bogs may have a higher rate of accumulation.

The CO_2 and CH_4 fluxes from undisturbed blanket bog are currently being studied in Co. Kerry. A limited study was also recently carried out of the CH_4 and CO_2 fluxes of an undisturbed raised bog in Midlands (Kiely 2003).

Only few studies have been carried out of the greenhouse gas fluxes of peat production fields and areas associated with peat harvesting. All of the studies have been conducted in Finland and Sweden, where significant amount of peat is extracted for energy production. According to Finnish study conducted by Nykänen et al. (1996), the average CO_2 emissions from the surface of a production field are 8 800 kg CO_2 ha^{-1} yr^{-1}. Measurements in Sweden carried out by Sundh et al. (2000) have indicated similar levels of CO_2 emissions, increasing from 0 to 10000 kg CO_2 ha^{-1} yr^{-1} for the first three years of draining and remaining at a constant level of 10000 kg CO_2 ha^{-1} yr^{-1} for the remaining time of the peat extraction. The emissions of CH_4 and N_2O in same studies were estimated to be small.

Finnish studies indicate average CH_4 emissions from drainage ditches to be 178 kg CH_4 ha^{-1} yr^{-1}, (Nykänen et al. 1996) while Swedish studies show smaller values, on average 52.5 kg CH_4 ha^{-1} yr^{-1} (Uppenberg et al. 2001). The peat stored in stockpiles and ridges can act as sources of greenhouse gases, measurements in Finland found the emissions of CO_2 to be around 1750 kg CO_2 ha^{-1} yr^{-1} (Nykänen et al. 1996).

Currently, only a minor part of the peat production fields in Ireland and in other countries has been brought under any after-use management practices. Consequently there are a limited number of studies of greenhouse gas fluxes in these situations. The greenhouse gas fluxes of forestry have been most extensively studied. Studies in Finland have shown the carbon accumulation of forestry on cutaway peatlands to be between 900-3800 kg ha^{-1} yr^{-1} (3330-14060 kg CO_2 ha^{-1} yr^{-1}) depending on the tree species (Table 5.2.2).

Table 5.2.2. Sequestration potential of cutaway forests in Finland.

Sequestration of carbon on different cutaway peatland forest sites in Finland	
Birch (Aro & Kaunisto 1998)	1650-2900 kg C ha^{-1} yr^{-1} (6105-10730 kg CO_2 ha^{-1} yr^{-1})
Pine (Aro & Kaunisto 1998)	900-2100 kg C ha^{-1} yr^{-1} (3330-7770 kg CO_2 ha^{-1} yr^{-1})
Short rotation forestry (willow/birch) (Hytönen & Kaunisto 1999)	1600-3800 kg C ha^{-1} yr^{-1} (5920-14060 kg CO_2 ha^{-1} yr^{-1})

However, these studies show only the potential of forest stands to sequester carbon. The peat soil under the stand is still affected by drainage and can therefore act as a source of greenhouse gases. Comprehensive studies do not exist on the carbon balances from peat soils, but it has been estimated that CO_2 emissions may be high (Crill et al. 2000). A study conducted by Byrne (1999) indicated that soil CO_2 emissions in Sitka spruce forest on blanket peat can be over twice that in undisturbed blanket bog.

Studies in Finland suggest that re-wetted peatlands (colonised with *Eriophorum vaginatum*) would sequester carbon annually at a rate of 1080-1600 kg CO_2 ha^{-1} yr^{-1}. CH_4 emissions for first three years of the wetland generation were low (5 – 15 kg CH_4

ha^{-1} yr^{-1}). However, the emissions are likely to increase when the re-wetted peatland matures (Tuittila et al. 1999).

Research is currently on underway into the greenhouse gas fluxes of rewetted industrial cutaway peatlands in Ireland. At least some vegetation types (*Typha latifolia and Eriophorum angustifolium*) will be likely to act as sources of CH_4 in rates higher than of Finnish studies described earlier (Wilson et al. 2003).

5.3 Lifecycle Analysis for Energy Use of Peat in Ireland

Although the majority of greenhouse gas emissions associated with the peat energy lifecycle are generated by the combustion process, the greenhouse gas balances of the other components of the cycle are a vital part particularly when considered over a long time scale. Figure 5.3.1. shows the carbon cycle of peat use for energy. At present there is insufficient information available to construct a full lifecycle analysis of peat use for energy in Ireland and its climatic impact. This relates primarily to greenhouse gas fluxes in peatlands prior to, during and after peat harvesting activities. Such lifecycle analysis is crucial to the classification of peat as a fossil or biomass fuel.

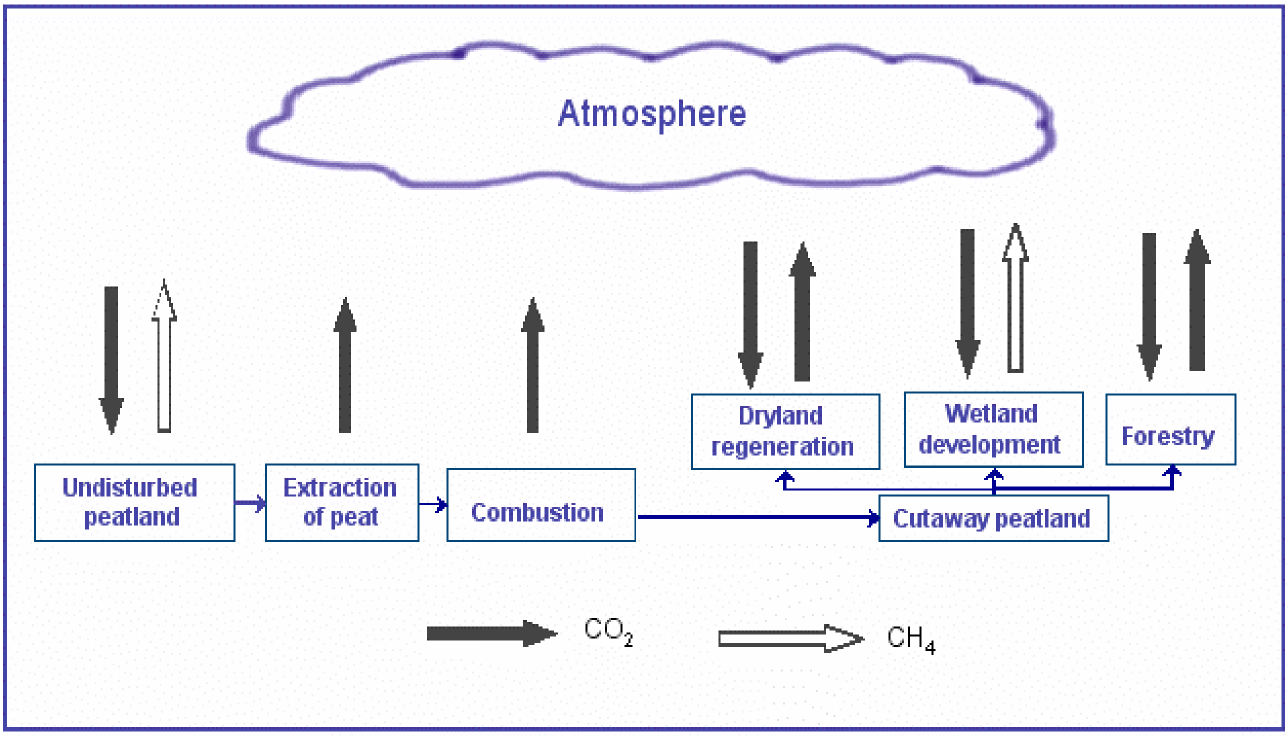

Figure 5.3.1. Carbon cycle of peat use for energy.

When considering the full peat energy lifecycle, the greenhouse gas balance of the peatland before peat harvesting must be included. For example harvesting peat from agricultural peatland is more beneficial from a climatic point of view than using undisturbed peatland. This is due to the high emissions associated with agricultural peatland (Maljanen et al. 2001 estimated the CO_2 emissions from agricultural peatlands to be about 15000 – 27500 kg CO_2 ha^{-1} yr^{-1}). Only pristine peatlands have been used for peat harvesting in Ireland and therefore the loss of carbon accumulation potential as well as the cessation of CH_4 emissions must be taken into account. Further research is needed on the greenhouse gas fluxes of undisturbed raised bog in order to provide a baseline against which to determine the loss of carbon accumulation potential and the cessation of CH_4 emissions following peatland development for peat harvesting.

The peat production fields have also their own greenhouse gas balances contributing to the climatic impact of the peat energy lifecycle. To date, no studies have been conducted on greenhouse gas fluxes in peat production fields in Ireland. Emission factors for calculating the emission levels in production fields do exist, but these are based on research carried out in other countries, which may not provide the best possible emission estimates in Ireland. For accurate estimation of the emissions from production fields in Irish conditions, research should be carried out on the emissions from peat production fields including the preparation of the production fields for peat harvesting and areas associated with peat production (i.e. ditches, boundaries).

The after-uses of cutaway peatlands can make a significant contribution to the greenhouse gas balance of the full peat energy lifecycle. Ideally, the after-use would create an ecosystem with the potential to act as a sink of carbon over a long period of time and therefore reduce the climatic impact of the whole peat energy chain. According to Mälkki & Frilander (1997) the carbon accumulation potential of cutaway sites restored to wetland could reduce the total net greenhouse gas emissions per energy unit produced by 5 – 10 % when a restoration period of 100 years is considered. Research is currently underway on the carbon balances of the after-uses, but more research is required on the greenhouse gas fluxes of forestry and wetlands generated on cutaway peatlands.

The combustion of peat is the biggest contributor to the greenhouse gas balance of peat use for energy. It has a climatic impact comparable to coal and therefore the short-term impact of peat energy is significant. The emissions generated from the combustion process can be quantified, although uncertainties exist especially regarding the emissions from the private combustion of peat.

6. Role of Peat in National Greenhouse Gas Balance

6.1 Greenhouse Gas Emissions in Ireland

Under the Kyoto Protocol, Ireland has committed to reduce the greenhouse gas emissions to 13% above the base year 1990 emissions. However, the current trend in emission level is increasing and Ireland is likely to face difficulties in reaching its emission reduction target. Emissions increased by 31% from 53.4 million tonnes CO_2 equivalent in 1990 to 70 million tonnes CO_2 equivalent in 2000. The increase of emissions is mainly due to growth of CO_2 emissions from the energy and transport sectors (McGettigan & Duffy 2003). The emissions of each gas and main sectors for base year and 2001 are shown in Table 6.1.1.

Table 6.1.1. Emissions of six greenhouse gases and sectors for base year (1990 for CO_2, CH_4 and N_2O, 1995 for HFCs, PFCs and SF_6) and 2001 (McGettigan & Duffy 2003).

Gas	***Base year emissions (million t CO_2 eq)***	***2001 emissions (million t CO_2 eq)***
CO_2	31,732	45,832
CH_4	11,900	12,563
N_2O	9,542	10,401
HFCs	20.7	231
PFCs	75.4	297
SF_6	83.1	66.8
Total	**53,352**	**69,389**
Sector	***Base year emissions (million t CO_2 eq)***	***2001 emissions (million t CO_2 eq)***
Energy	31,027	45,348
Industrial processes	3,145	4,050
Solvent and other product use	91.6	109
Agriculture	17,937	19,170
LUCL	-65.7	-629
Waste	1,217	1,341
Total	**53,352**	**69,389**

From the different sectors producing greenhouse gases, CO_2 emissions from fuel combustion (energy and transportation) make the most significant contribution to overall greenhouse gas emissions (McGettigan & Duffy 2003). Most of the energy required is produced in power plants and therefore those emissions are the most significant from the emissions from energy sector. The emissions from power plants using different fossil fuels are shown in Table 6.1.2.

Table 6.1.2. Greenhouse gas emissions from energy produced by power plants in 2001 (McGettigan & Duffy 2003).

Fuel	*Emissions CO_2 (Gg)*	*Emissions CH_4 (Gg)*	*Emissions N_2O (Gg)*
Peat	2667	0	0.3
Coal	6021	0	1.0
Fuel Oil	3925	0	0.7
Natural Gas	4186	0	0.2

6.2 Emissions from Peat Combustion

As described earlier, all stages of peat use for energy production, the initial stage of undisturbed peatland, extraction of the peat, combustion of peat in power plants and in private households, and the after-use of the peatland contribute to the total greenhouse gas budget. Greenhouse gas emissions can be calculated using activity data and emission factors (EFs). Activity data are statistical information used in emission calculation such as land area and production and consumption figures of fuels, while EFs are developed based on research and emission measurement information. The IPCC provides EFs for most processes producing greenhouse gases or EFs can be developed by individual countries (Houghton et al. 1997).

Emissions from peat combustion make up the largest share of the overall emissions of peat used for energy production. The majority of CO_2 emissions are created in power plants producing electricity. Peat burning power plants in Ireland do not have CO_2 analysers installed and therefore the emissions are calculated using EFs. The IPCC Guidelines for National Greenhouse Gas Inventories provide a CO_2 EF for peat burning power plants (106 t CO_2/t), but this factor is based on much lower moisture content (30%) of peat than is appropriate for Irish milled peat (Houghton et al. 1997). This has lead to power plant operators determining EFs applicable for each individual plant and the overall EF for power plants used in the national greenhouse gas inventory is based on these (Table 6.2.1). The EFs are based on the average moisture and carbon content of peat, measured heat rate and efficiency of the combustion process.

Table 6.2.1. EFs used in the National Greenhouse Gas Inventory (McGettigan & Duffy 2003).

Sector	*t CO_2/TJ*	*kg CH_4/TJ*	*kg N_2O/TJ*
Power plants	111.6	0	12
Residential sod peat	104	50	5
Briquettes	98.86	50	5
CHP	112.8	0	12

Table 6.2.2 shows emissions of peat combustion for different categories for 2001 based on the energy produced and above EFs.

Table 6.2.2. Emissions from peat combustion for 2001 (McGettigan & Duffy 2003).

Sector	*Emissions CO_2 (Gg)*	*Emissions CH_4 (Gg)*	*Emissions N_2O (Gg)*
Power Plants/Peat	2 667	0	0.28
Residential Peat	779	0.38	0.04
Residential Peat Briquettes	451	0.23	0.02
Commercial Peat Briquettes	17	0.008	0.001
CHP Peat	61	0	0.007
Total	**3975**	**0.618**	**0.348**

ESB power plants generate around 1800 Gg of CO_2 per year, emissions from Shannonbridge plant are the most significant, while emissions from the Bellacorrick plant are much smaller. The CO_2 emissions from Edenderry plant are around 900 Gg per year.

The majority of the CO_2 emissions from the whole lifecycle of peat use for energy are due to the combustion of the peat. Therefore, it is important to be able to estimate these emissions as accurately as possible. The emissions from peat combustion are currently reported under the UNFCCC. Compared to the emissions from other stages of energy use of peat, power plant emissions do not include high uncertainties, being 5.1% combined for the activity data and EFs (McGettigan & Duffy 2003). However, since peat combustion in power plants generates a major part of the overall emissions this will lead to significant variation in the total emission level. The EF includes higher uncertainty than the activity data. This is due to the calculation method and the power plants not having CO_2 analysers installed. The calculation of emissions without the possibility to verify with emission measurement data causes the uncertainty of the EF.

The uncertainty of emissions of peat burned by other sectors is 22.46%, significantly higher than for power plants EFs (McGettigan & Duffy 2003). This is high for both EFs and activity data. The amount of sod peat harvested by the private sector is based on estimates made by Bord na Móna. These estimated are based on available information of the energy markets, not on the actual amount of the peat produced. Private producers are not inclined to report the amount of peat harvested and therefore the uncertainty is likely to remain high. The emissions from actual combustion process include also higher uncertainties than the emissions from power plant combustion. Peat combusted by the private sector can be of varying quality, which is not monitored. The private sector also burns peat in small units of varying types, which contributes to high variation in the emissions from the combustion process. Overall, the emissions from the peat used by the private sector are estimates that include high uncertainty due to the lack of accurate activity data and information to develop EFs.

6.3 Emissions from Peat Production Fields

Currently, only the emissions of peat combustion are monitored and included in the National Greenhouse Gas Inventory of Ireland. The area currently under active peat extraction by Bord na Móna is 22 222 hectares. The area of peatland where extraction has ceased, but no after-use has taken place is 3 492 hectares. Other areas including reserves, surplus areas and unusable cutaways with bare peat surface bring the total amount of bare surface peatland area affected by peat extraction to 41 311 hectares. This area does not include other areas associated with peat extraction such as ditches, stockpiles, silt ponds, peatlands used by private sector or cutaway peatlands under after-use management practices.

Research has not yet provided country specific EFs for peatlands under peat extraction in Ireland. The IPCC has recently completed *"Good Practice Guidance for Land Use, Land Use Change and Forestry"* (IPCC 2004). The EFs used in this study are taken from this. These EFs are applicable for peatlands currently under peat extraction as well as peatlands where extraction has ceased but on which artificial drainage is still active. IPCC EFs are used in this study to calculate the emissions from Irish peatlands under peat extraction, even though they are based on only limited number of studies and therefore have high uncertainties. Table 6.3.3 shows the IPCC EFs, which are used in this study to estimate the emissions from peat production fields.

Table 6.3.3. IPCC EFs for nutrient-poor industrial peatlands in temperate regions.

EFs for Industrial Peatlands	
CO_2	200 kg C ha^{-1} y^{-1} (733 kg CO_2 ha^{-1} yr^{-1})
N_2O	0.1 kg N_2O-N ha^{-1} yr^{-1}

The alternative to using the IPCC emissions factors is to use country specific EFs. As mentioned earlier, EFs specific for Ireland do not yet exist. Finland has developed country specific CO_2 EF for peat production fields. In the Finnish National Greenhouse Gas Inventory (Ministry of the Environment 2003), 10600 kg CO_2 ha^{-1} yr^{-1} is used. This is a net emission figure based on the combined emission level (surface flux 8800 kg CO_2 ha^{-1} yr^{-1}, average annual loss of carbon accumulation 200 kg CO_2 ha^{-1} yr^{-1}, emissions from stockpiles 1750 kg CO_2 ha^{-1} yr^{-1} and from ditches 90 kg CO_2 ha^{-1} yr^{-1}). EFs for CH_4 and N_2O from peat production fields do not exist in Finland. The Finnish EF is used here to compare the emission levels calculated using alternative EFs. Table 6.3.4 shows emissions for Bord na Móna peatlands under peat extraction based on the land area and the IPCC EFs as well as Finnish EF.

Table 6.3.4. Greenhouse gas fluxes of Bord na Móna peatlands under peat extraction.

Greenhouse gas fluxes of peatlands under peat extraction	
CO_2 (IPCC EF)	30.3 Gg CO_2 y^{-1}
CO_2 (Finnish EF)	454.4 Gg CO_2 y^{-1}
N_2O	0.006 Gg N_2O/y^{-1}

Significant difference on the emission level calculated by using IPCC EFs and Finnish EF can be observed. Both EFs have limitations when used to calculate emissions from Irish peat production fields.

IPCC EFs are based on limited studies conducted in other countries and therefore include high uncertainties (135% for CO_2 and 300% for N_2O) (IPCC 2004). This will lead the emission levels to be somewhat hypothetical. The IPCC EFs can be used only to calculate emissions from production fields excluding the potential emissions from surrounding areas.

The Finnish EF is significantly higher than the IPCC EFs leading to the much more significant emissions. Finnish EF includes other areas affected by peat extraction and therefore may provide more comprehensive picture of the overall emissions. The EF is based on research conducted in Finland, where the climatic conditions differ significantly from Ireland, which is likely to increase the uncertainty of using the Finnish EFs in Ireland.

Since country specific EFs for Ireland do not exist, it is difficult to assess which of the EFs would be more suitable to use in Ireland to produce as accurate emission data as possible. If country specific EFs do not exist and IPCC is able to provide EFs, those should be used in the national greenhouse gas inventory. Using the IPCC EFs to calculate the emissions from production fields may however decrease the importance that peat production fields have on the total climatic impact on peat energy lifecycle even though research has proven that their contribution is significant (emissions from peat production fields have been identified as a key source of greenhouse gases in Finland). Nevertheless, comparing the emission levels obtained by using IPCC and Finnish EFs highlights the need of country specific EFs for peat production fields.

6.4 Emissions from Other Parts of Peat Lifecycle

In addition to the emissions from peat combustion and production fields, emissions are generated by other parts of the peat energy lifecycle that can not be quantified. Total of 80 000 hectares of peatland is influenced by Bord na Móna peat extraction and further 6000 hectares is extracted by the private sector. For part of that, approximately 40 000 hectares, emissions can be calculated using IPCC or Finnish EFs. This area includes active production area, bare peat reserves, bare cutaways and unusable cutaways.

The greenhouse gas balance of the rest of the peatland area cannot be calculated by using either of the EFs. These areas include drains, stockpiles, headlands, railbeds, vegetated reserves, and silt control areas. This area of over 30 000 hectares could significantly contribute to the total emissions from the peat extraction. These areas are peatlands affected by drainage, but due to for example vegetation cover could have significantly different carbon balances than the actual production fields. As described earlier, studies have been made to determine the emissions of ditches and stockpiles, proving that the emissions are generated from those areas as well.

The greenhouse gas budgets of after-use of cutaway peatland are highly important not only for gaining better understanding of the greenhouse gas profile of the whole lifecycle, but also for making sustainable decisions of the future land-use. The whole area of peatland used for peat extraction will become cutaway within next 20 years, leading to greenhouse gas balances of those areas to become highly important. Currently, over 10 000 hectares of cutaway peatland is under different after-use practices and the emissions from those areas have not been estimated. This will increase the uncertainty of the climatic impact of the whole lifecycle, and the longer the emission data from these areas does not exist, the higher the uncertainty gets (through more peatland become as cutaway).

6.5 Radiative Forcing of Peat Use for Energy

Based on the emission calculations, radiative forcing for peat combustion and production fields can be calculated (Table 6.5.1). Using the emission data and the global warming potentials of each gases, the relative radiative forcing of the emissions of CH_4 and N_2O compared to CO_2 can be assessed.

Table 6.5.1. Radiative forcing of peat combustion and production fields as CO_2 equivalent for 100 years time horizon.

	Annual flux (Gg)	Radiative forcing (W/m^2)
Peat combustion		
CO_2	3976	3976
CH_4	0.61	13
N_2O	0.35	110
Total for combustion	3977	4099
Peat production fields (IPCC)		
CO_2 (IPCC EF)	30	30
CO_2 (Finnish EF)	454	454
N_2O	0.006	2
Total for production fields (IPCC EF)	30	32
Total for production fields (Finnish EF)	454	456
Total for combustion and production fields (IPCC EF)	**4027**	**4131**
Total for combustion and production fields (Finnish EF for CO_2)	**4431**	**4555**

From the Table 6.5.1, the potential of three greenhouse gases to cool or warm the climate can be observed. The fluxes on CH_4 and N_2O are not significant compared to the flux of CO_2. However, the radiative forcing represents their impact compared to CO_2. The significance of CH_4 and N_2O emissions increases when emissions are expressed with radiative forcing.

7. Energy Use of Biomass in Ireland

Biomass is a renewable source of energy, because the CO_2 emissions from the combustion of biomass are compensated by the carbon that is sequestered during the growth of the plant. Therefore, biomass can be said to be a carbon neutral fuel. Ireland has a challenging greenhouse gas emission reduction target for the Kyoto Protocol's first commitment period and therefore all measures to reduce the emissions should be considered. Ireland's energy production relies heavily on carbon intensive fuels such as peat and partial substitution of those fuels with biomass could contribute to the reduction of greenhouse gas emissions.

Ireland does not have a long tradition of using biomass as a source of energy. Forest cover is one of the lowest in Europe and biomass sources have not been widely available. However, forest cover is increasing and the use of biomass in energy production is seen as one possibility to reduce greenhouse gas emissions as well as increase the domestic production of energy. Today approximately 2% of Ireland's energy supply come from renewable sources and 1.3% from biomass. At present, most biomass use is from burning industrial wood waste to produce heat by the wood processing industry (Rice et al. 1997).

Peat is the least carbon efficient fossil fuel producing more CO_2 per energy unit than oil, natural gas and coal. Replacing part of the peat with biomass fuels could significantly reduce the emissions from a peat burning power plant. Co-firing biomass in a peat burning power plant in Ireland has been indicated previously by a number of authors (e.g. Broek et al. 2000 and Rice 2003) to be a means to reduce greenhouse gas emissions in Ireland.

7.1 Availability of Biomass in Ireland

If biomass is to be used in co-firing with peat to generate electricity it needs to be available at a competitive price. This is currently not the case in Ireland. However, the energy markets may be subject to change in the future as a result of the effects of carbon taxation and the emission trading scheme. This may increase the costs of energy production by fossil fuels and therefore make biomass a more economically attractive alternative.

Several ways exist to produce the biomass needed by the power plants. In the short-term the most likely source of biomass is waste generation by different sectors. The forestry and timber industry generates waste both during the harvesting and processing of wood. In addition wood waste is generated by the commercial and private sectors. Biomass from purpose grown energy crops is likely to be available at a later stage, assuming that major energy crop plantations are established (Rice et al. 1997). Around 570 000 wet tonnes of biomass could be available currently or in the near future:

- Sawmill residues - 89 000 tonnes (COFORD 2003a)
- Forest residues and thinnings - 200 000 tonnes (Hoyne & Thomas 2001)
- Recovered wood e.g. from construction and demolition waste - 180 000 tonnes (EPA 2002, COFORD 2003b)
- Purpose grown energy crops - 90 000 tonnes (Rice et al. 1997).

Figure 7.1.1 shows the current or short-term potential to generate energy from biomass in Ireland. The availability of different biomass fuels for energy production is based on a small number of studies. The estimated wood waste and forest residues are currently available for energy use. The availability of energy crops is based on the available non-rotational arable set-aside land (10 000 ha) and average yield of poplar and willow of 9 oven dry tonnes ha^{-1} yr^{-1} (Rice et al. 1997). The total potential energy is calculated on the basis of calorific values and moisture contents of different biomass fuels (Alakangas 2000, Hoyne & Thomas 2001, Rice et al. 1997). The moisture content has a significant impact on the amount of energy a fuel produced for example the amount of forest residues available is higher than for recovered wood, but the energy producing potential is lower due to the high moisture content.

Figure 7.1.1 shows the potential electricity production by these biomass resources taking into account the moisture content and calorific value of different fuels and the efficiency of a peat burning plant (assumed 40%).

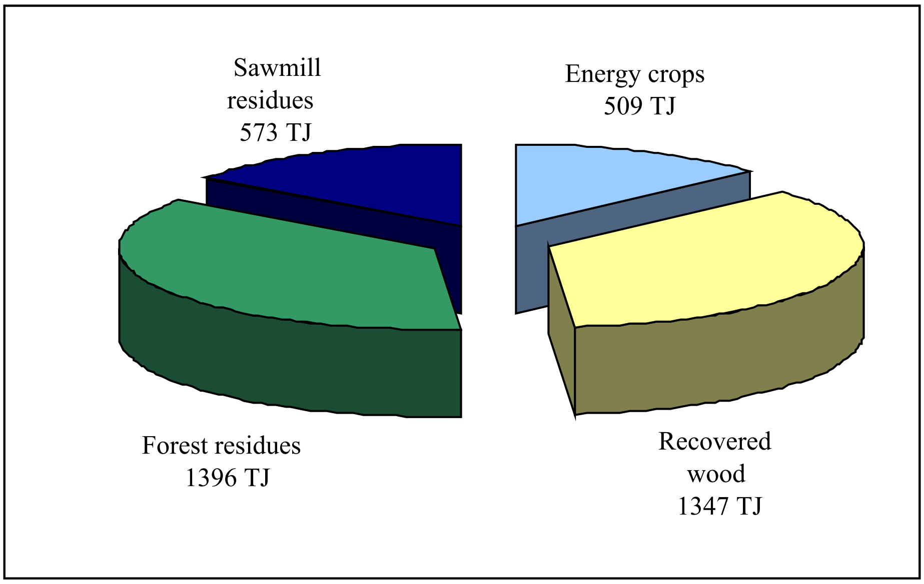

Figure 7.1.1. Potential energy generation from biomass in peat burning power plants.

In this study biomass is assumed to be combusted in a power production unit with 40% efficiency. The moisture content and the average calorific value of the fuels are also taken into account. This will bring the potential energy generated by these biomass fuels to approximately 3800 TJ per year. This is equivalent to over one third of the energy produced by the Edenderry power plant and the two new ESB power plants.

7.1.1 Energy Crops

Purpose grown short rotation energy crops could provide an attractive alternative for producing biomass for energy production. The ideal solution for producing biomass would be by growing the crops in cutaway peatlands. Cutaway peatlands are mostly situated in the Midlands, close to existing power plants. The infrastructure to transport the fuels also exists. However, trials of growing short rotation crops, willow (*Salix)* and poplar *(Populus*) species carried out by Bord na Móna in late 1970s were disappointing. Of the 400 hectares of energy crops cultivated, only 10% performed moderately well. The target yield of the trial, 12 tonnes of dry matter per hectare, was not achieved on any part of the cultivated area. Based on the trials, it was concluded by Bord na Móna that due to the nature of cutaway sites, the costs of preparing the sites (mainly increasing the pH) would be too high for economically viable production of energy crops (Bord na Móna 1988).

According to available information, short rotation crops will grow more successfully on mineral soils. The land used for energy crop production could be former non-rotational arable set-aside and existing pasture. The midlands and south-east are likely to be the most suitable for short rotation forestry, but potential sites can be found in all parts of the country (Rice et al. 1997).

Trials conducted by Teagasc (Irish Agriculture and Food Development Authority) indicated that willow and poplar species would be the most viable energy crop species harvested in five-year (or less) rotation. Yields of 7-11 oven dry tonnes ha^{-1} yr^{-1} have been obtained for willow and up to 13 oven dry tonnes ha^{-1} yr^{-1} for poplar (Rice et al. 1997).

Other potential energy crop species include perennial grasses such as *Mischanthus* and hemp. Both can provide good yields, but problems may arise from the varying moisture content, storage and transportation.

Currently, the growing of short rotation forestry is not economically attractive on agricultural land in Ireland. Unlike conventional forestry and agriculture, energy crop production does not receive grants. This does not encourage farmers to grow these crops. Considering the economic and other difficulties associated with growing of energy crops, they are not likely to provide a significant source of energy in the near future. However, in the longer term, production of energy by energy crops in smaller scale power production or as a supplementary fuel with other biomass and fossil fuels in larger power production units has potential.

7.1.2 Forest Residues

Ireland has some of the best climatic conditions for forestry in Europe, but with under 10 % forest cover, the lowest proportion of forest coverage in the EU (Bacon 2003). About 600 000 ha of land is currently afforested in Ireland, and the area is increasing. Timber is mainly produced for fibreboard, structural use and joinery. In addition to timber, forestry activities, such as thinning and clearfelling, produce residues that are left to decay in the forest. These residues can be used in energy production. The methodology to collect the forest residues is not yet available in Ireland, but examples from other countries show that this can indeed be done. It is estimated that 200 000 tonnes of dry forest residues could be harvested annually (Rice et al. 1997).

To transport the forest residues to energy production plants, residue collection and transportation system needs to be established. The transportation of the residues may involve high costs since many of the forests are situated far from the peat burning plants. The impact of residue collection on biodiversity and the productivity of the forest stand should also be considered. The removal of residues may affect nutrient availability in forest sites, therefore its impact on forest productivity and biodiversity should be considered.

7.1.3 Sawmill Residues

The wood processing industry produces residues in sawmills and board factories in the form of wood chips, bark and sawdust. These residues are currently the only significant source of energy produced from biomass in Ireland (Rice et al. 1997).

Sawmill residues would be a suitable alternative energy source in peat burning power plants. However, most of these residues are already utilised by the wood processing industry and therefore may not be available for such use. It is questionable if transferring their use for energy generation in peat burning power plants would be the most sustainable alternative. COFORD estimated (COFORDa) that 89 000 tonnes from the total amount of sawmill residues could be available for energy use outside the wood processing industry.

7.1.4 Recovered wood

Currently, significant amounts of wood waste are generated each year in Ireland. Most of this potential biomass fuel is not yet utilised, but disposed of to landfill. Using this resource might provide an economically viable option for peat burning plants to produce energy from biomass fuels. The disposal fees on landfills are likely to increase and in future it may become economically more feasible to use this resource, rather than to dispose of it to landfill.

A significant amount of recoverable wood are created by construction and demolition activities and packaging. Due to recent economic growth, Ireland has generated large quantities of waste from these activities. In 1998, around 2.7 million tonnes of construction and demolition waste was generated. Of this waste, approximately 14% or 380 000 tonnes is wood and therefore can be potential source of energy (EPA 2002). Part of this amount of wood has been treated with for example paints or solvents and can not be used in energy production as it is. Clean recovered wood is treated as carbon neutral fuel, but treated wood is not and therefore would not be of interest to power producers. It has been estimated than approximately 100 000 tonnes of untreated or engineered wood, which could be used in energy production was generated in 2000 in Ireland. Without improvement in waste reduction, projected increases of 130 000 to 160 000 tonnes by 2005 are estimated (COFORDb 2003).

Wood is also used extensively in packaging mostly by the commercial sector in the form of wood pallets, crates and boxes. In 1998, an estimated 85 000 tonnes of wood packaging was created. A significant share of that is already recycled, but part is still disposed of to landfills (EPA 2002).

Few obstacles exist to using this resource for energy. Using wood waste for energy production may be considered as incinerating waste, and therefore waste incineration licences may be required. Treated wood waste is not considered as a carbon neutral fuel, and therefore potentially subject to carbon taxation in the future. Additional problems may be raised from the sorting, collection and processing of the waste.

7.2 Co-firing of Peat and Biomass in the Edenderry Power Plant

One of the main objectives of this study is to assess the potential for replacing a portion of the peat burned in the Edenderry power plant with biomass from recovered wood. In the long term other biomass sources may be more suitable to be used in large-scale energy production, but in the near future recovered wood provides the most realistic source of biomass energy. The wood material is potentially available and is not used for any other purpose. Therefore, the time-scale on which this resource could become in use is less than, for example, for energy crops.

Before recovered wood can be used as a fuel, it has to be collected, separated and processed. This would likely to be done by an operator independent from the power generator in a purpose build collection and processing facility. Ideally the facility would be situated between Dublin and Edenderry, since recovered wood is mostly generated in urban areas. This would minimise the transportation distances.

The Edenderry power plant was commissioned in 2000 as the first of three new fluidised bed power plants using peat in Ireland. The plant is more efficient than old peat burning plants. These plants operated at average 26% efficiency while the Edenderry plant can operate at over 38% efficiency. This leads to an average reduction of 38% in the amount of CO_2 produced per unit of energy produced (Department of the Environment and Local Government 2001).

Table 7.2.1. Edenderry power plant (Reilly 2003).

Edenderry Power Plant	
Electricity production capacity:	118 MW
Boiler:	Bubbling fluidised bed boiler
Efficiency:	38 %
Fuel:	Milled peat supplied by Bord na Móna Average moisture content 55 % Calorific value 7.7 MJ/Kg
Fuel consumption:	1 million t/yr

In the fluidised boiler, peat burns in a bed of sand that is agitated by the combustion air. Peat is fed at a controlled rate to keep the temperature of the bed at an average of 800 - 900°C. Fluidised bed systems can handle a wide variety of biomass fuels. The Edenderry plant is built to burn peat, but there are no major technical obstacles to replace part of the peat with biomass.

This would however require administrative efforts such as undergoing environmental assessment procedures if the plant is going to be changed to use biomass fuels. Changes would also be necessary to infrastructure, storage and handling facilities. Transporting significant quantities of fuel by road is likely cause problems in a plant vicinity, where most of the roads are not planned to handle heavy transportation. The problem has not existed with peat since peat is transported by railway from near-by production areas. Edenderry Power has estimated that with the current infrastructure, up to 20% of the fuel could be transported to the plant by road.

Edenderry Power Ltd has a fuel supply agreement with Bord na Móna until 2015. Based on that agreement, Edenderry power has to purchase one million tonnes of peat annually. Therefore, if co-firing would be considered, biomass would be burned in addition to peat (plant has a capacity to burn 1.2 million tonnes of fuel per year), the fuel supply agreement would have to be renegotiated or Bord na Móna would have to act as the supplier of the biomass.

In this study, the current practice of Edenderry Power plant, burning only peat, was chosen as a reference system. Co-firing of recovered wood with peat was chosen as the most likely alternative to produce energy by biomass in Edenderry in the short-term. The recovered wood would replace part of the peat combusted so that the same amount of energy is produced annually that would be with one million tonnes of peat combusted. The amount of energy produced annually by the plant is 3000 TJ.

The carbon cycle energy use of peat has been described earlier (chapter 5.) as well as the problem of the insufficient information available to quantify the contribution that each stage of peat energy lifecycle has on the total greenhouse gas balance. This increases the difficulty to compare the climatic impact of the whole peat lifecycle to other energy lifecycles. Figures 7.2.1 and 7.2.2 represent the carbon balances of the biomass system and sole combustion of peat.

It can be assumed that with the current practice of using peat for energy production in Ireland, the emissions from combustion are the most significant and the total lifecycle of peat energy has a warming impact on the climate. Peat use for energy would have a cooling impact on the climate if more carbon were to be accumulated by peatlands formerly used for peat harvesting than is released by the production and combustion process. The peat energy lifecycle however generates more greenhouse gas emissions than is accumulated in peatlands and therefore peat use for energy has a net warming impact on the climate. Using biomass in energy production does not have this warming impact, since the carbon that is released during the combustion process can be assumed to be sequestered by plants.

The carbon cycle of peat use for energy is shown in the Figure 7.2.1. Estimates of the amount of carbon released or accumulated can be made for a part of the lifecycle, while for other parts the carbon balance can only be estimated qualitatively.

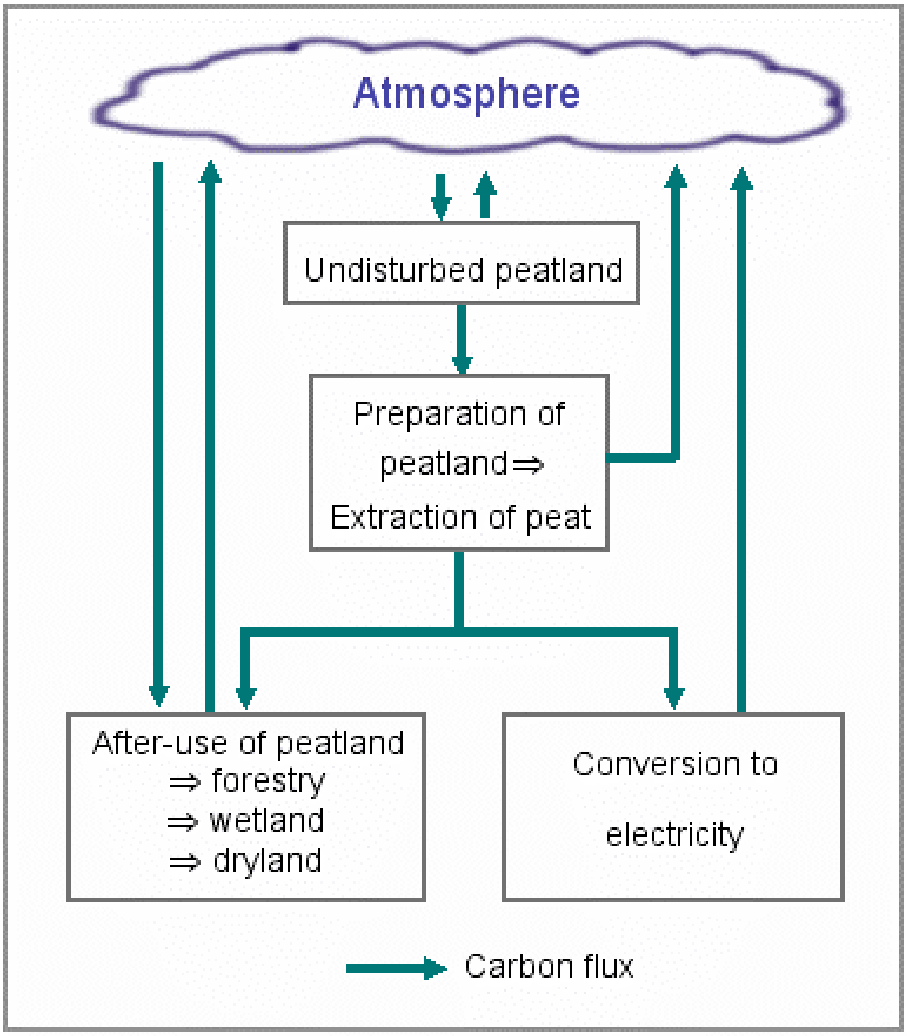

Figure 7.2.1 Carbon cycle of the lifecycle of peat use for energy.

Recovered wood combustion process is assumed not to generate greenhouse gas emissions, due to sequestration of carbon by forests. Part of the carbon sequestered is not released in the recovered wood and peat co-firing process, but earlier on in the lifecycle. After the harvesting of wood, an estimated 23-35% of the above ground biomass of trees is left to decay in the forest (Rice et al. 1997). Processing the harvested wood to make wood products also generates residues that are mostly used within the wood processing sector to produce energy or as raw material by particleboard and horticultural sectors. Around 50% of the roundwood harvested is converted to sawnwood to be used by the building sector. The carbon bound in the remaining residues is released in a time-scale depending on the use (energy production – instant release of carbon, particleboard production – slow release of carbon after the end of the life of the particleboard has been reached).

The remaining amount of wood is used as a building material. At this stage, part of the wood is discarded as waste and can be used in energy production. The rest of the wood will become available for energy production after the buildings have been demolished. Currently, most of the wood from construction and demolition activities is disposed of to landfill. At landfill, bacteria cause the wood to decompose, under partially anaerobic conditions, producing biogas. This biogas consists primarily of CH_4 and CO_2 in the ratio of 2:1 (Irish Energy Centre 2000). Ideally, all of the wood from construction, demolition and packaging activities would be used for energy production. This would lead to avoided greenhouse gas emissions from landfill. In practice, part of the wood is likely to end up in the landfill and some amount of emissions will be generated. Figure 7.2.2 shows the carbon cycle of recovered wood and peat combustion process.

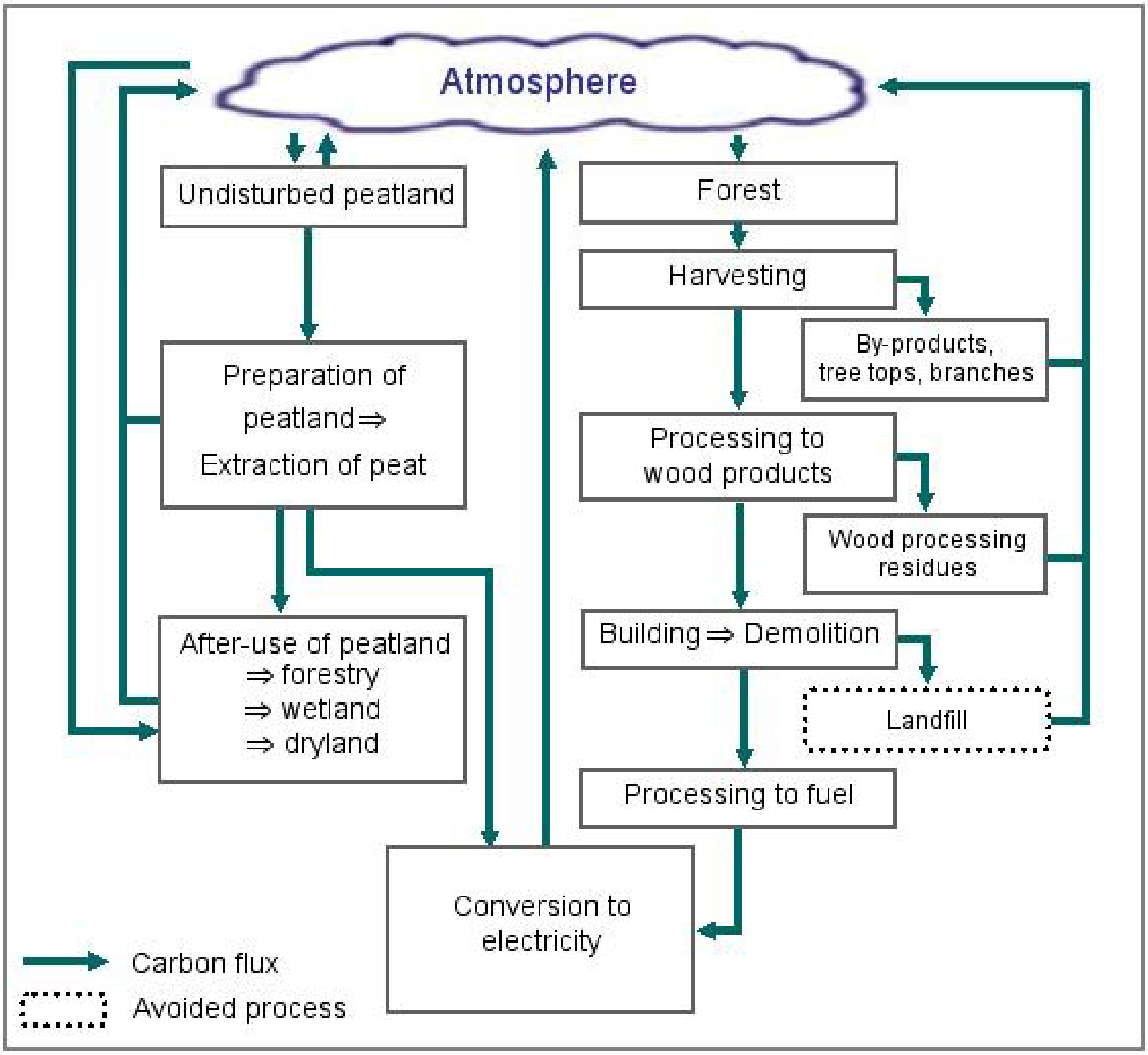

Figure 7.2.2. Carbon cycle of co-firing peat and recovered wood

Due to information gaps described earlier (Chapter 5), the carbon balances of the lifecycles of co-firing recovered wood with peat and sole combustion of peat can be only compared qualitatively. In this study, the potential emission reduction of the combustion process is quantified. As stated, the emissions from the peat combustion process have the biggest contribution to the carbon balance of the peat energy lifecycle. Therefore the emission reduction by the combustion process has the most significant impact on improving the carbon profile of the peat energy lifecycle. Recovered wood is considered to be a carbon neutral fuel, and therefore, the emission reduction is equivalent to the carbon that would be emitted by peat that is replaced by wood. Figure 7.2.3 demonstrates the potential CO_2 emission reduction when replacing a proportion of the peat used with recovered wood.

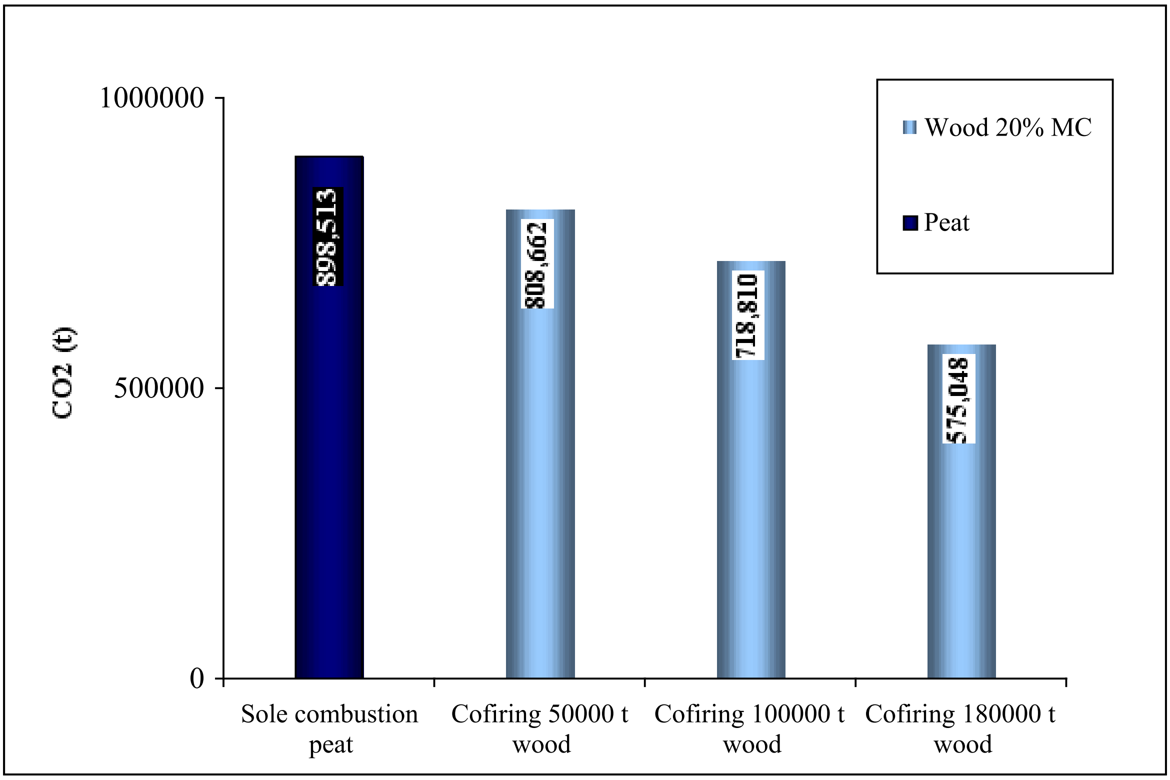

Figure 7.2.3. Potential CO_2 reduction with co-firing peat with recovered wood.

The emission reduction of co-firing peat with 50 000 tonnes, 100 000 tonnes and 180 000 tonnes of recovered wood can be seen. Co-firing 50 000 tonnes of recovered wood decreases the need of peat to 900 000 tonnes, 100 000 tonnes of wood to 800 000 tonnes of peat and 180 000 tonnes of wood to 640 000 tonnes of peat. Recovered wood is assumed to have 20% moisture content and has heating value of 15.4 MJ/kg. This is significantly higher than the heating value of peat (7.7 MJ/kg), which leads to more energy being produced with smaller amount of fuel.

Potentially, the emissions reduction by co-firing could range from 70 000 tonnes of CO_2 per year to 320 000 tonnes of CO_2 per year. This translates to an emission reduction between 8% to 36%. Co-firing with 180 000 tonnes of recovered wood (the total available amount of untreated recovered wood in Ireland) would lead to a significant emission reduction. This is however not realistic since the total volume of recovered wood available for use in Edenderry is likely to be smaller than the actual recovered wood produced and the infrastructure may not allow this large amount to be transported by road to the plant.

Realistic emissions reduction in the short-term would likely to be between 8-15% with a maximum of 100 000 tonnes of recovered wood combusted per year.

7.3 Future of Co-firing Peat and Biomass in Irish Peat Burning Power Plants

By 2005, three new fluidised bed peat burning power plants will have replaced the old plants that have been producing energy from peat for decades. In addition to these new power plants being more efficient, they can burn biomass without major retrofitting. In total these plants are expected to use three million tonnes of peat per year producing on average 9000 TJ of electricity per year. The greenhouse gas emissions from these plants will be around 270 0000 tonnes of CO_2 per year.

Individual plant would benefit from the emission reduction with the possibility of trading the emission permits saved due to the cofiring biomass. Currently the national emission permit allocation plan under the EU's emission trading scheme does not require significant emission reductions to be made by the peat energy producers within next few years. However, stricter emission reductions may be required in the future. This is likely to increase the price of energy produced by peat and other fossil fuels and therefore make energy production from biomass a more attractive alternative. In the near future, more information will become available of the future price of carbon, which will have an impact on costs of the production of energy from biomass in the future.

The availability of biomass for energy production is likely to increase in the future in Ireland. Forest cover is increasing and with more favourable economics of biomass production, other biomass production activities are likely to become more common. The new peat burning power plants operate most efficiently when the moisture content of the fuel is relatively high. Biomass is often considered to have too high moisture content for efficient energy generation. The moisture content of forest residues and energy crops can be quite high which may decrease their usability in some power production units. The high moisture content is not a disadvantage for the new peat power plants, but an actual requirement if a large proportion of peat is going to be replaced by other alternative fuels.

If the price of carbon and therefore the costs of energy production from fossil fuels are going to increase significantly, other sources of biomass may be considered in addition to those discussed earlier. Waste management practices are still evolving in Ireland and part of the waste stream currently disposed of to landfill has potential as a biomass fuel. The Edenderry Power has already considered co-firing small amounts of meat and bone waste with peat. This waste is particularly problematic since it can not longer be used as animal fodder and other uses are also limited. Currently, the waste is transported abroad to be further treated. Meat and bone waste is considered a carbon neutral fuel, has low a moisture content and high heating value. Although it may be used in the future, its potential use as a fuel remains controversial in Ireland.

The availability of biomass for energy production is likely to increase with developing energy markets in the future. Even with current estimated biomass resources, around one third of the energy produced by peat could be produced by biomass.

References

Alakangas. 2000. Suomessa käytettävien polttoaineiden ominaisuuksia (Properties of Fuels Used in Finland). Technical Research Centre of Finland. Espoo, Finland

Armstrong, W. 1979. Aeration in Higher Plants. *Advances in Botanical Research*, 7:192-197

Aro, L., and Kaunisto, K. 1998. Forestry Use of Peat Cutaway Areas in Finland. In: Sopo, R. The Spirit of Peatland – 30 years of the International Peat Society. Proceedings of the International Peat Symposium. Jyväskylä. Finland

Bacon, Peter & Associates. 2003. Forestry: A Growth Industry in Ireland. Wexford, Ireland

Berdowski, J., Guicherit, R. and Heij, B. (editors). 2001. The Climate System. AA Balkema Publishers. Lisse, The Netherlands

Bord na Móna. 1988. Options for Development of Bord na Móna Cutaway Bogs.

Bord na Móna. 2002. Annual Report and Accounts 2002

Broek, van den R., Teeuwisse, S., Healion, K., Kent, T., Wijk, van A. and Turkenburg, W. 2000. Potential for Electricity Production from Wood in Ireland. *Energy*, 26: 991-1013

Brooks, S. and Stoneman, R. 1997. Conserving Bogs – The Management Handbook, The Stationary Office Ltd, Edinburg

Byrne, K. 1999. Studies on the Carbon Balance in a Blanket Peatland Forest. Forest Research Ecosystem Group. University College Dublin

Chanton, J.P., Bauer, J.E., Glaser, P.A., Siegel, D.I., Kelley, C.A., Tyler, S.C., Romanowich, E.H. and Lazrus, A. 1995. Radiocarbon Evidence for the Substrates Supporting Methane Formation within Northern Minnesota Peatlands. *Geochimica et Cosmochimica Acta*, 50(17): 3663-3668

COFORD. 2003a. The Potential of Wood Biomass as a Source of Renewable Energy in Ireland. Dublin

COFORD. 2003b. Potential to Recover Wood from Construction and Demolition Activities in Ireland Presentation in: Effective Management of Wood Waste Conference. Dublin

Crill, P., Hargreaves, K. and Korhola, A. 2000. The Role of Peat in Finnish Greenhouse Gas Balances. Ministry of Trade and Industry. Helsinki, Finland

Cruickshank, M.M., Tomlinson, R.W., Devine, P.M. and Milne, R. 1998. Carbon in Vegetation and Soils of Northern Ireland. In: Proceedings of the Royal Irish Academy. 98B (1), 9-21

Department of the Environment and Local Government. 2001. Progress Report – Implementation of the National Climate Change Strategy. Dublin

EPA 2002. Strategy for Developing Recycling Markets in Ireland - Wood. Dublin

Feehan J. (editor) 1994. Climate variation and Climate Change in Ireland. UCD Environmental Institute. Dublin

Feehan, J. and O'Donovan, G. 1996. The Bogs of Ireland. University College Dublin

Foss, P.J. 1998. National Overview of the Peatland Resource in Ireland. In: towards conservation strategy for the Bogs in Ireland. Irish Peatland Conservation Council. Dublin

Foss, P.J. and O'Connell, C.A. 1996. Irish peatland Conservation Plan 2000. Irish Peatland Conservation Council. Dublin

Foss, P.J., O'Connell, C. A. and Crushell, P. H. 2001. Bogs and Fens of Ireland – Conservation Plan 2005. Irish Peatland Conservation Council. Dublin

Gorham, E. 1991. Northern Peatlands: Role in the Carbon Cycle and Probable Responses to Climatic Warming. *Ecological Applications*, 1(2): 182-195

Hammond, R.F. 1981. The Peatlands of Ireland. An Foras Talúntais. Dublin

Hillebrand, K. 1993. The Greenhouse Effects of Peat Production and Use Compared with Coal, Natural Gas and Wood. Technical Research Centre of Finland. Espoo.

Houghton, J. T., Meira Filho, L.G., Lim, B., Treanton, K., Mamaty, I., Bonduki, Y., Griggs, D.J. and Callander, B.A. 1997. Revised 1996 IPCC Guidelines for National Greenhouse Inventories. IPCC/OECD/IEA, Paris, France

Hoyne, S. and Thomas, A. 2001. Forest Residues: Harvesting, Storage and Fuel Value. COFORD. Dublin

Hytönen, J. and Kaunisto, S. 1999. Effect of Fertilization on the Biomass Production of Coppiced Mixed Birch and Willow Stands on a Cutaway Peatland. *Biomass and Bioenergy* 17: 455-469

IPCC. 2001. Climate Change 2001: The Scientific Basis. Cambridge University Press. Cambridge. UK

IPCC. 2004. Good Practice Guidance for Land Use, Land Use Change and Forestry

Irish Energy Centre. 2000. Landfill Gas in Ireland - The Facts. Co. Cork, Ireland

Jones, S.M. and E.P. Farrell. 2000. Research Programme to Develop a Forest Resource on Industrial Cutaway Peatland in the Midlands. BOGFOR 3 Project - Phase 1. Final Report. Forest Ecosystem Research. University College Dublin

Joosten, H. and Clarke, D. 2002. Wise Use of Mires and Peatlands. International Mire Conservation Group and International Peat Society. Devon, UK

Kiely. G. 2003. Carbon Dioxide and Nitrous Oxide Fluxes from Grasslands. In EPA Conference: Pathways to a Sustainable Future. Dublin

Lappalainen, E. 1996. Global Peat Resources. International Peat Society. Jyskä, Finland

McGettigan, M. and Duffy, P. 2003. National Inventory Report 2003: Ireland – Greenhouse Gas Emissions 1990-2001 Reported to the United Nations Framework Convention on Climate Change. Environmental Protection Agency. Wexford

McQuade, O. 2003. Energy Ireland Yearbook. 2003. Bmf Publising Ltd. Moira, Northern Ireland

Maljanen, M., Martikainen, P., Walden, J. & Silvola, J. 2001. CO_2 exchange in an organic field growing barley or grass in eastern Finland. *Global Change Biology,* 7 (6): 679-692

Ministry of the Environment. 2003. Greenhouse gas emissions in Finland 1990–2001 - National Inventory Report to the UNFCCC Secretariat. Finland

Minkkinen, K. and Laine, J. 2001. Turpeen käytön kasvihuonevaikutusten lisätutkimuskartoitus, Ministry of Trade and Industry, Helsinki

Mälkki, H. and Frilander, P. 1997. Lifecycle assessment of peat utilisation in Finland. Espoo. Technical Research Centre of Finland.

Moore, J.J., Dowding, P. and Healy B. 1975. Glenamoy, Ireland. *Ecological Bulletin*. Stockholm

Nykänen, H., Silvola, J., Alm, J. and Martikainen, P.J. 1996. Fluxes of Greenhouse Gases CH_4, CO_2 and N_2O on some Peat Mining Areas in Finland. In: Northern Peatlands in Global Climatic Change, Proceedings of the international Workshop held in Hyytiälä, Finland, 8-12 October 1995. The academy of Finland. Helsinki

Otte, M. L (editor) 2003. Wetlands of Ireland. University College Dublin Press. Dublin

Reilly, J. 2003. Personal Communication – Edenderry Power Plant

Rice, B., Bulfin, M., Kent, T., Fröhlich, A. and Lenehan, J .J. 1997. Potential for Energy Production from Agricultural and Forest Biomass in Ireland. Teagasc. Dublin

Rice, B. 2003. Energy Crops – Have They a Future. Teagasc. Dublin

Roulet, N.T., Ash, R., Quinton, W. and Moore, T. 1993. Methane Flux from Drained Northern Peatlands: Effect of a Persistent Water Table Lowering on Flux. *Global Biochemical Cycles*, 7(4)

Savolainen, I., Hillebrand, K., Nousiainen, I. and Sinisalo, J. 1994. Greenhouse impacts of the Use of Peat and Wood for Energy. Technical Research Centre of Finland. Espoo.

Shier C. 2003. Personal communication – Current and Future Land-use of Bord na Móna Peatlands

Sundh, I., Nilsson, M., Mikkelä, C., Granberg, G., and Svensson, B.H. 2000. Fluxes of Methane and Carbon Dioxide on Peat-mining Areas in Sweden. Ambio, 29 (8):499-503

Tuittila, E-S, Komulainen, V-M., Vasander, H., and Laine, J. 1999. Restored Cutaway as a Sink of Atmospheric CO_2. *Oecologia,* 120: 563-574

Tuittila, E-S. 2000. Restoring Vegetation and Carbon Dynamics in a Cut-away Peatland. PhD thesis. University of Helsinki

UNFCCC. 2003. Kyoto Protocol – Status of Ratification. Available from: www.unfccc.int/resource/kpstats.pdf. Accessed: 15/7/2003

Uppenberg, S., Zettenberg, L. and Åhman, M. 2001. Climate Impact from Peat Utilisation in Sweden. Swedish Environmental Research Institute Ltd. Stockholm

Wilson, D., Byrne, K., Alm, J., Farrell, E.P. and Laine, J. 2003. Methane Fluxes from Industrial Cutaway Peatland: Preliminary results. In Agricultural Research Forum. Tullamore

Appendix 1.

Emissions from peat combustion						
CO_2						
	Energy produced/TJ	EF/kg/CO_2/TJ	Kg CO_2	Gg CO_2	GWP (1)	Radiative forcing (2)
Power Plants/ Peat	23907	111577	2667429832	2667	1	2667
Residential Peat	7494	104000	779414688	779	1	779
Residential Peat Briquettes	4564	98860	451158682	451	1	451
Commercial Peat Briquettes	167	98860	16556282	17	1	17
GHP Peat	544	112800	61395235	61	1	61
Total	**36676**		**3975954720**	**3976**		**3976**
CH4						
	Energy produced/TJ	EF kg/CH_4/TJ	Kg CH_4	Gg CH_4	GWP (1)	Radiative forcing (2)
Power Plants/ Peat	23907	0	0	0	21	0
Residential Peat	7494	50	374719	0.4	21	7.9
Residential Peat Briquettes	4564	50	228181	0.2	21	4.8
Commercial Peat Briquettes	167	50	8374	0.0	21	0
GHP Peat	544	0	0	0	21	0
Total	**36676**		**611273**	**0.6**		**12.8**
N2O						
	Energy produced/TJ	EF kg/N_20/TJ	Kg N_20	Gg N_20	GWP (1)	Radiative forcing (2)
Power Plants/ Peat	23907	12	286880	0.29	310	88.9
Residential Peat	7494	5	37472	0.04	310	11.6
Residential Peat Briquettes	4564	5	22818	0.02	310	7.1
Commercial Peat Briquettes	167	5	837	0.00	310	0.3
GHP Peat	544	12	6531	0.01	310	2.0
Total	**36676**		**354538**	**0.35**		**109.9**

(1) IPCC (1996) Global warming potential for 100 years time horizon
(2) Radiative forcing as CO_2 equivalent
Emission factors and energy production information from EPA

Appendix 2.

Emissions from peatland managed for peat extraction (IPCC emission factors)								
CO_2 emissions								
	Area	EF kg/CO_2-C/ha/yr	Kg/C/yr	Conversion	Kg/CO_2/yr	Gg/CO_2/yr	GWP (1)	Radiative forcing (2)
Active production surface	22222	200	4444400	3.7	16296133	16.3	1	16.3
Area formerly under peat production/bare cut-away	3492	200	698400	3.7	2560800	2.6	1	2.6
Reserves/bare peat	8165	200	1633000	3.7	5987667	6.0	1	6.0
Unusable cut-away - small blocks	7432	200	1486400	3.7	5450133	5.5	1	5.5
Total	41311		8262200		30294733	30.3		30.3
N_2O Emissions								
	Area	EF kg/N_2O-N/ha/y	Kg/N/y	Conversion	Kg/N_2O/y	Gg/N_2O/yr	GWP (1)	Radiative forcing (2)
Active production surface	22222	0.1	2222.2	1.6	3492	0.0035	310	1.1
Area formerly under peat production/bare cut-away	3492	0.1	349.2	1.6	549	0.0005	310	0.2
Reserves/bare peat	8165	0.1	816.5	1.6	1283	0.0013	310	0.4
Unusable cut-away - small blocks	7432	0.1	743.2	1.6	1168	0.0012	310	0.4
Total	41311				6492	0.0065		2.0

Source of area data: Bord na M—na
Emission factors: IPCC
(1) IPCC (1996) Global warming potential for 100 years time horizon
(2) Radiative forcing as CO_2 equivalent

Emissions from peatland managed for peat extraction (Finnish emission factors)				
CO2 emissions				
	Area	EF kg/CO_2/ha/y	Kg/CO_2/y	Gg/CO_2/yr
Active production surface	22222	11000	244442000	244.442
Area formerly under peat production/bare cut-away	3492	11000	38412000	38.412
Reserves/bare peat	8165	11000	89815000	89.815
Unusable cut-away - small blocks	7432	11000	81752000	81.752
Total	**41311**		**454421000**	**454.421**

Source of area data: Bord na M—na
EF: National Greenhouse Gas Inventory of Finland

Appendix 3.

Potential energy production by peat and recovered wood in Edenderry power plant

Sole combustion of peat

	Fuel input (tonnes)	TJ (net CV basis)	GJ (net CV basis)	MWh	GWh	CO2 (tonnes)
Peat	1000000	7700	7700000	2138889	2139	898513
Net energy produced		2952	2952180	820050	820	
Total net energy produced		2952	2952180	820050	820	

Cofiring with 50000 tonnes recovered wood MC 20%

	Fuel input (tonnes)	TJ (net CV basis)	GJ (net CV basis)	MWh	GWh	CO2 (tonnes)
Peat	900000	6930	6930000	1925000	1925	808662
Net energy produced		2657	2656962	738045	738	
Biomass	50000	769	769243	213679	214	
Net energy produced		295	294928	81924	82	
Total net energy produced		2952	2951890	819969	820	

Cofiring with 100000 tonnes recovered wood MC 20%

	Fuel input (tonnes)	TJ (net CV basis)	GJ (net CV basis)	MWh	GWh	CO2 (tonnes)
Peat	800000	6160	6160000	1711111	1711	718810
Net energy produced		2362	2361744	656040	656	
Biomass	100000	1538	1538487	427357	427	
Net energy produced		590	589856	163849	164	
Total net energy produced		2952	2951600	819889	820	

Cofiring with 180000 tonnes recovered wood MC 20%

	Fuel input (tonnes)	TJ (net CV basis)	GJ (net CV basis)	MWh	GWh	CO2 (tonnes)
Peat	640000	4928	4928000	1368889	1369	575048
Net energy produced		1889	1889395	524832	525	
Biomass	180000	2769	2769276	769243	769	
Net energy produced		1062	1061741	294928	295	
Total net energy produced		2951	2951136	819760	820	

NOTES:

Net calorific value (peat)	7.7	MJ/Kg
Net calorific value (recovered wood MC 20%)	15.384868	MJ/Kg
1KW=	3.6	MJ
1MW=	3.6	GJ
1GW=	3.6	TJ
Plant efficiency=	38.34	%
CO2 emission factor=	116.69	t CO2/TJ