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PEAT, CARBON DIOXIDE PAYBACK AND WIND FARMS

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Contents

Summary

Peat is a unique plant material that holds water in a colloidal state in a virtually oxygen-free environment. This prevents the decay of plant remains thus trapping carbon for as long as the peat remains undisturbed. Such carbon sinks are among the largest reservoirs of trapped carbon (and hence carbon dioxide, CO_2) on earth.

Wind farm construction on a peat-rich site has an immediate adverse effect on atmospheric carbon dioxide in three ways. Firstly, the turbines and tracks destroy the biological surface which actively ‘fixes’ CO_2 from the atmosphere. Secondly, the fabrication and transportation of wind turbines generate CO_2 and thirdly, site construction utilises materials which also generate significant CO_2. Two further longer term effects are the irreversible changes brought about by the construction process to the stable, colloidal nature of peat leading to its ultimate decomposition and release of large quantities of entrapped carbon as CO_2, and lastly the increased CO_2 emitted from fossil-fired power stations running inefficiently in back-up mode for those times when the wind is not blowing.

The CO_2 debt of a wind farm has to summate all these factors. Only then can the true payback time be estimated. Although such estimates can only be approximate, and will vary from site to site, this analysis suggests that the payback time of wind farms on peat-rich sites will be significantly longer than the 3 to 18 months usually quoted by the wind power industry. This must bring into question the validity of building wind farms on such sensitive sites. This paper examines these sources of CO_2 and the extent to which they impact on the calculation of payback time.

1 Introduction

Construction of wind farms in the UK is driven by two government objectives. The **first** is the desire to generate electricity from renewable forms of energy to help close the imminent shortfall in UK electricity provision. The **second** is the need to reduce greenhouse gas emissions – a commitment made under the terms of the Kyoto Protocol. Under this agreement, the Government seeks to reduce a basket of six such gasses to 12.5% below the 1990 level by 2008-12, 20% by 2020, and with an aspiration to reach 60% reduction by 2050. The most significant of these gases is carbon dioxide (CO_2). The strategies adopted to achieve these objectives include capital grants for off-shore wind farm construction and a lucrative subsidy scheme for operators of both on- and off-shore wind farms (the Renewable Obligation Certificate scheme [ROC]). The ROC scheme imposes extra cost on conventional power stations, significantly increasing costs to the consumer.

It is generally accepted that wind farm electricity is almost free of CO_2 emission at the point of generation. However, there is a considerable CO_2 cost incurred both before and after operation commences. This paper addresses the nature and magnitude of the CO_2 costs/savings balance. In particular it assesses this balance in relation to peat-rich sites.

The CO_2 debt arises from four main sources:

1. loss of blanket bog (or trees if the site requires clear felling) that can 'fix' CO_2 from the atmosphere and store it in plant tissue;
2. CO_2 generated in the manufacture and transportation of the wind turbines;
3. CO_2 generated in the installation of the wind turbines (mainly cement production, rock crushing and related transportation);
4. release of stored CO_2 from within soils and peat disrupted during the excavation of turbine access tracks, infrastructure and bases, and that caused by adjacent collateral damage.

Each of these aspects is considered in order to estimate the CO_2 debt and payback time of wind farms. Only after this CO_2 debt has been repaid can a wind farm contribute to the Government's CO_2 reduction targets. The calculations are complicated by a lack of agreement as to which fuels are saved by wind generation (gas typically produces two to three times less CO_2 than coal) and the extent of the efficiency and capital cost penalty imposed on conventional plant operating as short-term reserve or 'shadow back-up' to cover for periods of low or very high wind.

The carbon debt will be higher when a wind farm is constructed on active blanket bogs, which are mainly distributed in the north and west of the British Isles (Figure 1)[1] or on an inactive bog comprising deep peat deposits which continue to hold massive reserves of stored CO_2. Notably, there are also other areas of the UK where CO_2 stores are significant,

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[1] Joint Nature Conservation Committee website, www.jncc.gov.uk.

such as some flood plains, the Broads and parts of East Anglia where sedge peat is abundant.

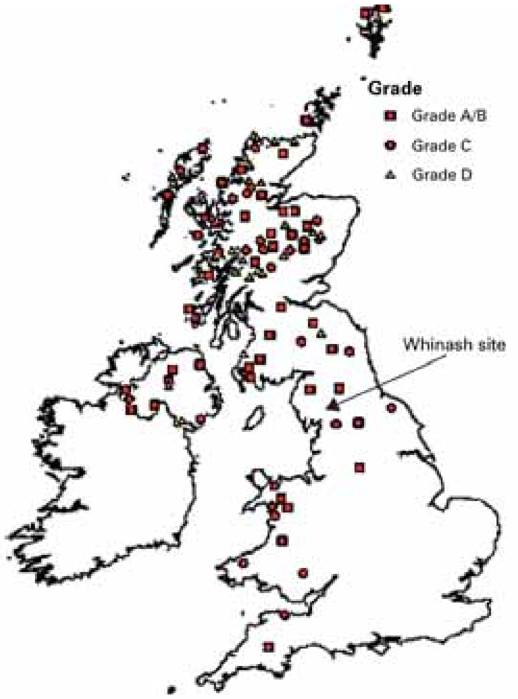

Figure 1: Major sites of blanket bog and peat deposits in the UK

So that the principles behind the calculations can readily be appreciated, the figures which follow relate to a hypothetical wind farm consisting of:

- a single turbine of 2.0 megawatt (MW) installed capacity (typical of many now being erected);
- an access track 0.5 km long and 5 metres wide – this length is the average per turbine calculated from planning applications or Environmental Impact Assessments (EIA) for 10 wind farms in the UK (range 0.23km to 0.77km);
- an average depth of peat of one metre.;
- no trees on site require felling.

The area of damaged bog around turbine bases and tracks is usually minimised in planning applications and EIAs, for obvious reasons. Good evidence, which is discussed later, exists to show that the damage is much more extensive than claimed. To make allowances for this, three scenarios are proposed for assessing peat damage. These are derived from a detailed study by Richard Lindsay[2] of the EIA accompanying AMEC and British Energy's original application for a wind farm on the Isle of Lewis peatlands. The scenarios are defined as follows:

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[2] Lindsay R, *Lewis wind farm proposals – observations on the official Environmental Impact Statement,* RSPB, May 2005.

- The ***low scenario*** (typical of that used explicitly or implicitly by developers) generally assumes that peat is destroyed at the site of turbine bases, hard standings and borrow pits or beneath access tracks and that collateral damage extends between five and ten metres from the sides of these constructions (here 10 metres on either side of access tracks and around other constructions is assumed);
- The ***medium scenario*** allows for damage to peat extending outwards for a further 50 metres from the sides of turbine bases, access tracks (total width 125m) and borrow pits;
- The ***high scenario*** allows for damage to peat extending outwards for 100 metres from the sides of turbine bases, access tracks (total track damage, 225m) and borrow pits.

To avoid ‘double counting’ the area of damage where access tracks terminate at a turbine base or pass close by (i.e. share overlapping areas of damage), the total length of track should be decreased by 2%, 15% and 30% for the low, medium and high scenarios respectively.

On typical lowland sites devoid of peat, the *low scenario* would apply. For many upland sites on dry or shallow peat, the *medium scenario* best describes how the peat might behave over time while for wet, peat-rich sites with active blanket bog the *high scenario* is the most likely. Local knowledge will guide in the selection of the most appropriate scenario for any given site.

The calculations are ***not*** detailed or absolute forecasts of how a given site will behave following intrusive construction activity. They are, however, reasonable approximations based on well-understood properties of peat soils, recognised constants and conversion factors, and industry-standard publications.

A final appendix applies this methodology to calculate the payback time for the proposed Whinash wind farm (Cumbria), drawing on information provided in the planning application and Environmental Impact Assessment.[3]

2 Peat

Several types of peat deposit are recognised in the UK but only two, raised mires and blanket bogs, will be considered here. They may be found in a variety of situations but mainly in the North and West where rainfall is high and temperatures moderate: Many are located within Special Areas of Conservation [SACs] designated under the EU Habitats Directive. Many **raised mires** arise within confined basins such as scooped-out valley bottoms which, inevitably tend to be waterlogged. They often evolve over millennia as broad domes where the peat has risen above the surrounding water table. They are fed

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[3] From West Coast Energy, Environmental Statement and Supplementary Environmental Information.

only by rain water, thus ensuring that they are nutrient-poor. **Blanket bogs**, as the name implies, form over large areas on relatively flat or undulating terrain, mainly in polar, sub-polar and temperate regions where temperature is generally low, rainfall is high and drainage is poor. They comprise the vast tracts of land known as tundra and are most notably represented in the UK in areas such as Rannoch Moor and the Isle of Lewis peatlands in Scotland. Blanket bogs can also occur on sloping sites such as mountain tops where rainfall is very high and drainage is impeded by geology or topography (i.e. the land contours). For example, substantial peat deposits two metres deep exist on the Twelve Bens in County Galway where the land slope is 25 per cent.[4] A third type of peat deposit, **fen peat,** occurs predominantly in low-lying areas, sometimes adjacent to blanket bogs or raised mires, where there is some water flow and nutrient enrichment. More detailed definitions of these habitats can be found on the web site of the Joint Nature Conservation Committee.[5]

The **natural** rate of growth of peat deposits varies widely with the prevailing climatic and local conditions but when optimal the rate of increase may reach one metre every 1000 years. Most peat bogs grow at a lower rate of between 10cm and one metre per millennium but, if conditions become unfavourable, they may stop growing altogether. Whatever the growth rate, peat provides a material with extraordinary stability compared to most other forms of vegetable matter. Many of the peat deposits in the northern hemisphere have been laid down since the last major period of glaciation some 10-15,000 years ago and may reach depths of 6 metres or even more. Much, though not all of this, arises from the bog mosses of the species *Sphagnum*.

On a global scale it has been estimated that there is more CO_2 stored in *Sphagnum* and *Sphagnum* litter lying above the peat layers than in any other genus of plant[6] – estimated as 550 X 10^6 tonnes, two to three times more than is stored in higher plants in tropical rain forests. However, the largest stores of carbon dioxide are present in the peat of the arctic tundra, estimated as 107 thousand million tonnes in tussock tundra and 53 thousand million tonnes in wet sedge tundra[7] – or between 6 and 7 times the current total annual worldwide CO_2 emissions of 24 thousand million tonnes.[8] Notably, in the UK, there is more carbon dioxide sequestered in peat than in all the trees and flowering plants in the UK and France combined.[9]

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[4] Bellamy D (1986), ‘The Wild Boglands’, *Bellamy’s Ireland,* Chapter 3, p. 57.

[5] www.jncc.gov.uk, Heading 7130, *Blanket bogs, Description and ecological characteristics.*

[6] Clymo R S & Hayward P M (1982), ‘The ecology of Sphagnum’, in A J E Smith (ed.), *Bryophyte Ecology*, 229-89. Chapman & Hall (London).

[7] Miller P C, Kendall R & Oechel W C (1983), ‘Simulating carbon accumulation in northern ecosystems’, *Simulation*, Vol 40: 119-31.

[8] Current estimates can be obtained from the Energy Information Administration of the US Dept. of Energy: http://eia.doe.gov/.

[9] RFERAC Conference, Durham University, July 2004.

Clearly, climate change that resulted in wholesale thawing of the tundra would have the potential to release significant quantities of CO_2 (and methane) into the atmosphere. This is all the more reason why our existing peatland should be protected from adverse human interference such as wind farm construction and commercial peat harvesting.

2.1 The biological nature of peat

The solid components of peat consist largely of partly decomposed remains of plants preserved in an acidic, waterlogged and oxygen-free environment. These conditions prevent further breakdown of the remains by inhibiting the growth of micro-organisms. For the same reason, well preserved human remains hundreds or thousands of years old are sometimes found in peat deposits.

The main generators of peat are mosses (especially the bog mosses of the species *Sphagnum*), and sedges – both plants that can tolerate very wet conditions in which the nutrient level is low. There are lesser contributions from rushes and some specialised bog plants. The preservation of plant materials in peat is so complete that many individual species can be identified even in peat cores thousands of years old. Also well preserved are pollen grains and spores that can provide valuable information about variations in past plant coverage and climate.

Even if a blanket bog has stopped growing, the peat formed over previous millennia is a reservoir for trapped carbon. As long as the bog remains intact this store will also remain *in situ*. If the peat is dried and exposed to air it breaks down, the plant materials oxidise and the carbon is released as CO_2 (see box).

Carbon or Carbon Dioxide?

Plants take up carbon dioxide from the atmosphere and combine it with water using the energy of sunlight to form carbohydrates. In so doing they release oxygen. The carbohydrates in turn form the structure of plants (mainly lignin and cellulose). Thus plant tissues contain carbon rather than carbon dioxide *per se*. However, when plant material is burned or is allowed to decompose the structural components recombine with oxygen and release the CO_2 back to the atmosphere.

Some documents refer to carbon accumulation or emission while others refer to carbon dioxide. To convert carbon values to carbon dioxide multiply the former by 44, the molecular weight of CO_2, and divide by 12, the atomic weight of carbon. For example, 48 grammes of carbon is equivalent to 176 g of CO_2 (48 X 44/12 or approx. 48 X 3.67).

2.2 The physical nature of peat

The solid plant remains in undrained blanket bog and raised mires contribute only 5% to 10% of the volume. Most of the remaining ‘pore-space’ is occupied by water. Hence, waterlogged peat has a solid content similar to that of milk and may, simplistically, be likened to porridge. It is, therefore, highly unstable and is capable of moving or flowing across the ground – a phenomenon known as a ‘bog burst’ or peat slide. This occurs naturally from time to time in the UK[10] or during wind farm construction such as the occurrence at Derrybrien in County Galway in the Irish Republic in October 2003.

It would be misleading, however, to suggest that the water within peat is liquid water. Rather, it exists in the form of a ‘colloid’. An example of a colloid would be a jelly. These comprise 90% water but it does not ‘run out’ when the mould is upended onto a plate. This is prevented by chemical interactions between the suspended particles in the jelly and the water which ‘lock’ the water into place within the structure. But to what extent does this apply to peat?

To answer this it is first necessary to look at the generalised structure of a peat bog and the underlying peat deposit (Figure 2).

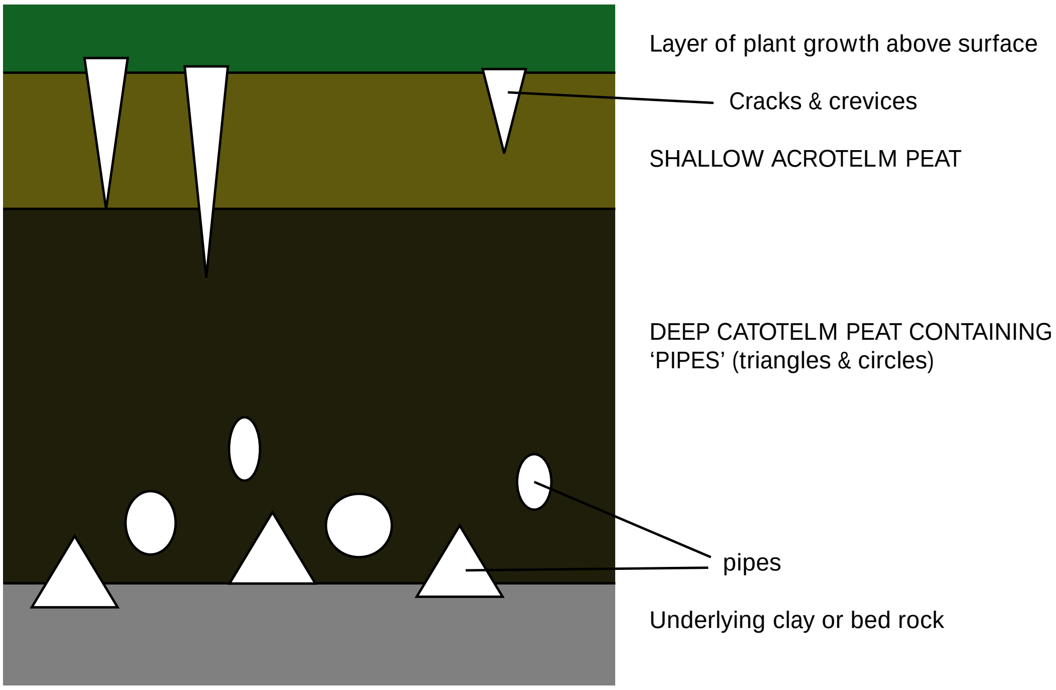

Figure 2: Cross section through a peat bog

On the surface is the active zone of plant growth (mosses, sedges, rushes and other bog plants). Below this is a layer between 10 and 30cm thick called the **acrotelm** (Figure 3). This is not colloidal in nature and can be penetrated by rain water and by atmospheric oxygen. It is also the region where plant roots penetrate. Rain water falling on the bog either drains away in surface runnels or through the acrotelm, or collects in surface bog pools. Within the acrotelm, limited decomposition of plant remains takes place, leading to the build up of peat.

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[10] ‘Bog Bursts’, by John Tallis, *Biologist*, V. 48(5), 218-23, 2001.

Figure 3: A drainage ditch over 2 metres deep at Cefn Croes wind farm showing surface vegetation, the acrotelm as the light brown upper peat layer about 30cm thick and underneath it the dark brown, waterlogged catotelm

Below the acrotelm is the bulk of the peat mass, or **catotelm**. Within this zone, water is trapped in colloidal form and is constant and almost static – i.e. there is almost no water exchange, it just sits there. Also there is no oxygen penetration. These conditions give rise to an anaerobic, acid environment (pH 4 to 5) in which little further decay can take place. Of course there are variations within the catotelm from area to area, including the existence in some places of small passages within the peat or at the interface between the catotelm and the underlying clay or bed rock. These are called ‘pipes’ and may serve as drainage channels in periods of very heavy rainfall.

It will be evident from this description that the catotelm is a very static structure with little exchange of water or gasses. However, it is vulnerable during periods of drought and very sensitive to human interference. During extreme drought, the acrotelm may dry out, shrink and crack. If this is prolonged, the cracks can penetrate deeper into the peat mass to create vertical fissures. When the drought is over, these fissures remain because the colloidal nature of the saturated catotelm cannot be reconstituted. Over time such fissures may enlarge, thus producing permanent damage. Such actions contribute to the formation of bare peat ‘cliffs’ (known as peat haggs) frequently encountered on upland sites. Human activities such as peat harvesting, digging drainage ditches, over-grazing, or even hill walking can also result in similar changes in the catotelm, leading to initiation of peat oxidation and carbon dioxide release.

It is of note that wind farm developers are often aware of the special nature of peat deposits. Hence, applications frequently refer to the ‘careful removal and storage of peat’ and its replacement in cable trenches and the like. But peat is a unique material and once the continuous colloidal peat-bulk has been breached it can never be restored. Erosion and oxidation are inevitable. This is why contractors try to avoid digging out blanket peat whenever possible. Instead, they construct what are termed ‘floating roads’. Though these might avoid the actual removal of some peat, the constant vibration and compression will inevitably add to the degradation of the underlying catotelm, the appearance of drainage pipes and the slow oxidation and erosion of the peat mass.[11] Such roads often sink into the peat below, sometimes quite rapidly.

3 Carbon dioxide arising from wind farm construction and operation

3.1 Loss of carbon dioxide fixing capacity through bog surface damage

In considering this aspect of the CO_2 cost of a wind turbine it is noted that the uptake of CO_2 from the atmosphere will vary from bog to bog and will be influenced by several factors including mean annual temperature, rainfall, altitude, proximity to the sea, and latitude. It will be highest in bogs which are classed as **active** in which there is a near complete coverage of growing *Sphagnum* bog moss which is contributing new peat.

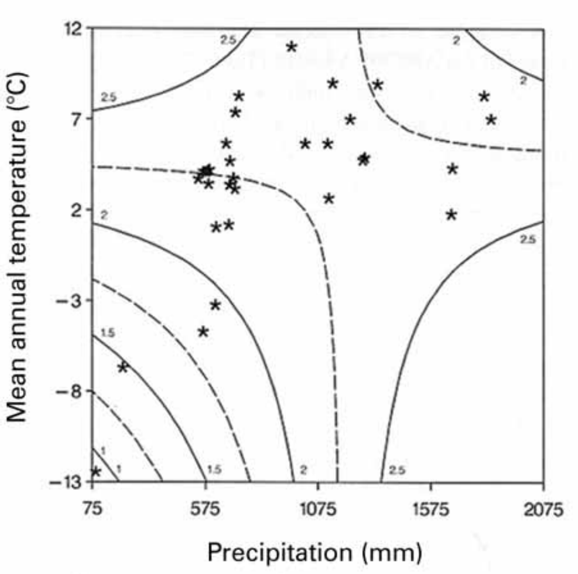

Figure 4: Sphagnum productivity in relation to temperature and rainfall.

The values on the contour lines are the productivity in grammes per square metre per year expressed as $\log_{10}$ values where a value of 1, 1.5, 2 and 2.5 correspond to 10, 32, 100 and 316g/m^2/year respectively.

A recent study explored the factors influencing *Sphagnum* growth (and thus CO_2 fixation).[12] It concluded (Figure 4) that the rate of growth of *Sphagnum* at 31 different locations was most influenced by temperature and rainfall. The absolute productivity of *Sphagnum* ranged widely from 8 to 1,450 grammes per square metre per year with a

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[11] Lindsay R (2005), *Lewis wind farm proposal – observations on the official EIA*, p. 30.

[12] Gunnarson U (2005), ‘Global patterns of Sphagnum productivity’, *Journal of Bryology*, Vol. 27: 269-79.

mean of $259\text{g/m}^2\text{/yr} \pm 206$. This equates to 259 ±206 tonnes per square kilometre. However, most of this matter is water and does not represent the actual accumulation of carbon.

The true long-term carbon accumulation rate has been estimated by others in growing peatlands to be in the region of 29 grammes of carbon per square metre per year[13] (29 tonnes per $\text{km}^2\text{/yr}$) or 106 tonnes of $CO_2\text{/km}^2\text{/yr}$ removed from the atmosphere. Although this may seem a small amount it has to be borne in mind that northern and sub-arctic peatlands (equating to 85% of the world's peatlands) are estimated to cover 3.5 million km^2 of the earth's surface[14] which means a total annual sequestration of CO_2 of 371 million tonnes (cf: UK emissions are about 550 million tonnes/year).[15]

Many bogs in the UK today are drier than in the past due to human draining activity or over-grazing and may have lower growth rates than those cited above. This is evident from the carbon accumulation rates given for the Isle of Lewis peatlands application site[16] which range from 17 to $24\text{g/m}^2\text{/year}$, but as low as $9\text{g/m}^2\text{/year}$ in burned mires and even zero for badly eroded or heavily drained mires. In the calculation here, a conservative figure of $19\text{g/m}^2\text{/yr}$ is used.

Figure 5: Typical 5 metre wind farm track with collateral damage extending to the sides at the Ffynnon Oer wind farm, Vale of Neath

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[13] Gorham E (1991), 'Northern peatlands: role in the carbon cycle and probable responses to climate warming', *Ecological Applications*, Vol 1, 182-95.

[14] O'Neill K P (2000), 'Role of bryophyte-dominated ecosystems in the global carbon budget', in Shaw A J & Goffinet B (eds), *Bryophyte Biology*, Cambridge University Press.

[15] For latest emissions data see DEFRA: http://www.defra.gov.uk/environment/statistics/globatmos/gaemunece.htm.

[16] Isle of Lewis peatlands wind farm application, AMEC & British Energy, Appendix 18B.

Using this figure, the loss of CO_2 uptake from the atmosphere can be calculated for a track of 0.5km and a single turbine. For the *low scenario* it is assumed that the track is 5 metres wide and that collateral damage (ditching, cable trenches and damage caused by large earth moving vehicles) extends for 10 metres on either side (Figure 5), i.e. the damaged width will be 25 metres.

Hence track damage will be 12,250m^2 (500 m long X 25 m wide less 2 per cent).[17] To this has to be added the damage caused by the turbine base (Figure 6). From on-site experience, this is likely to cover an area of at least 900 m^2 (hole 20 metres square plus 5 metres of damage in each direction = 30 m X 30 m). To this must be added the crane hard-standing area of 1000m^2 (50 m X 20 m). Thus the total damaged blanket bog surface will be 12,250 +900+1,000 = 14,150m^2.

Figure 6: Damaged bog surrounding a turbine base at Derrybrien wind farm (Irish Republic). Also shown are dumps of peat left to oxidise, tracks and drainage ditches.

14,150m^2 multiplied by 19g carbon sequestered per m^2 per year gives 268,850 gC or 0.269 tonnes of carbon per year. This translates to 0.99 tonnes of CO_2. As this damage is permanent, the total loss of CO_2 fixation in the 25 years' life of this hypothetical wind farm

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[17] The areas of damage around access tracks and turbine bases will sometimes overlap. To avoid double-counting the area of damage the track length should be reduced by 2 percent for the *low scenario*, by 15% for the *medium scenario* and by 30 per cent for the *high scenario*.

will be 24.7 tonnes (rounded up to 25 tonnes for subsequent calculations), though it will be ongoing even after decommissioning.

3.2 Carbon dioxide emissions during fabrication and transportation

In discussing this aspect, it is recognised that the construction of all power stations (nuclear, coal, gas, hydro, tidal barrage, wind) have an energy, and thus a CO_2, 'cost': it is not an aspect unique to wind. At least two publications[18] [19] from the wind industry have tried to address this issue. Both stress the imprecise nature of the calculations due to the many assumptions that have to be made. It should be noted that the calculations refer to the primary energy used in fabricating a wind turbine and neither have addressed the issue of CO_2 release from disturbed and degraded peat.

Milborrow concluded that *'….the energy payback for wind almost invariably lies in the range between 3 and 10 months'.* However, figure 4 in his paper (see Figure 7) shows a range from 3 months to 30 months but this is not explained. It should be noted that this study only appears to address the actual fabrication and construction of turbines. No details are given regarding transportation and erection. Carbon dioxide emissions from peat damage are not considered at all.

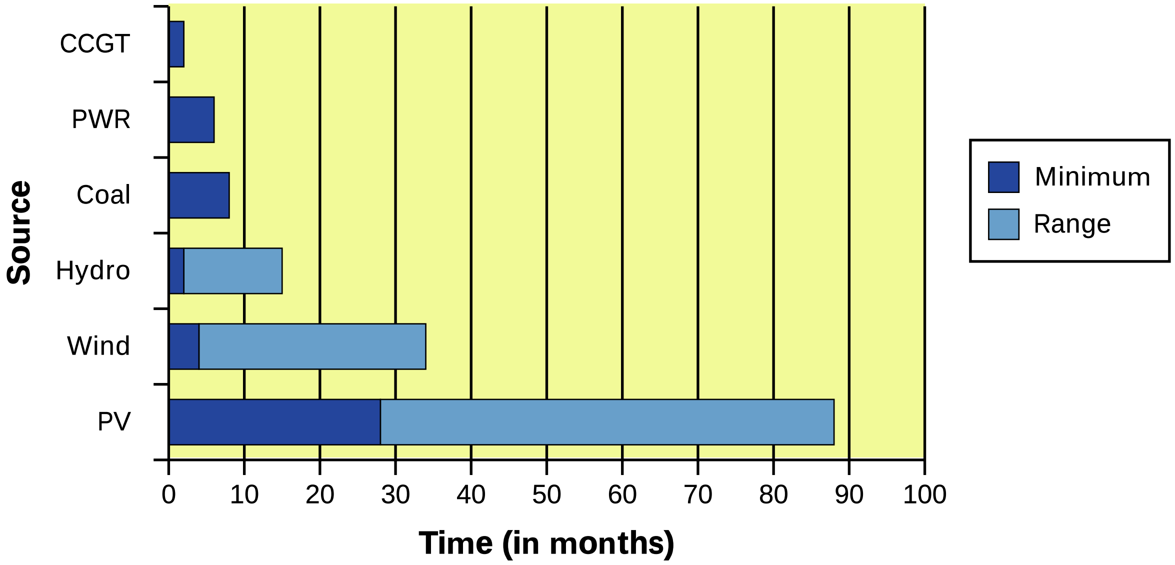

Figure 7: Energy payback time for wind compared with some other electricity generating sources (from Milborrow, 1998, footnote 19).

CCGT = Combined Cycle Gas Turbine; PWR = Nuclear Pressurised Water Reactor; PV = Solar Photovoltaic

The paper also states that the energy used in manufacturing and installing a 600 kW turbine is 830 megawatt hours (MWh) but it is not clear whether this includes concrete

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[18] Krohn, S (Ed: for the Danish Wind Turbine Manufacturers Assn.) 'The energy balance of modern wind turbines', *Windpower* Note, No 16, December 1997.

[19] Milborrow D (1998), 'Dispelling the myths of energy payback time', *WindStats Newsletter*, Vol. 11 (2).

and track construction on site. This is equivalent to 1,383MWh per turbine megawatt. Although there may be some economies of scale, turbine manufacture is energy-intensive, utilising very large steel forgings, and economies are unlikely to be enough to alter the basic argument.

Using the figures of Milborrow an approximate calculation can be made of the CO_2 debt incurred in the manufacture of the 2MW turbine postulated in the model considered here. To derive this, the electricity consumed has to be converted into emissions from the generating plants, which will differ from country to country and over time. Hence, the CO_2 emissions from 2,766 MWh of electricity used in manufacture (2 X 1,383MWh) will depend on the type of fuel used to generate it. Nuclear power has close to zero CO_2 emissions, coal in the region of 0.86 tonnes per MWh and gas about 0.3 tonnes per MWh. The currently accepted grid average emission figure is 0.43 tonnes per MWh. If the fuel used was coal the manufacturing process would produce 2,378 tonnes of CO_2 (2,766 X 0.86). If the grid average emissions figure was used it would be half that.

For the purposes of this paper we will use the figure of 2,378 tonnes as no allowance has been made for the CO_2 debt arising from the transportation by sea and road of the turbine.

3.3 Carbon dioxide emissions during on-site construction

A concrete turbine base for a 100 metre high turbine is typically 15 metres square and 1-2 metres deep (say 1.5 metres) so the volume of concrete needed will be 337 cubic metres. High strength concrete will be used at 2.4 tonnes/m^3. Hence, the tonnage of concrete needed will be 337 x 2.4 = 810 tonnes. On top of this base is a collar to which the steel tower will be bolted and this will typically add approximately 50 tonnes of concrete. Together with incorporated steel (about 32 tonnes) (Figure 8) and concrete in the load-bearing stands for cranes, blade and hub support, the total mass used will be in the region of 1,000 tonnes per turbine.

Cement manufacture is among the worst of human activities for CO_2 generation. This is largely due to (i) the energy used in driving the rotary kilns and (ii) the slaking of lime (a process called calcining) which releases CO_2 directly to the atmosphere. Estimates have been made of the total CO_2 emission from these processes ranging from 0.36 to 1.25 tonnes of CO_2 per tonne of cement,[20] [21] depending on the type of process used, the cement/clinker ratio and the fuel used. In the calculations below 0.8 tonnes of CO_2 per tonne of cement has been assumed which is consistent with a recent EC guidance.

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[20] IEA Greenhouse Gas R&D Programme from Ecosys Energy and Environment and Berkeley National Laboratory (*Emission Reduction of Greenhouse Gasses from the Cement Industry – see* http://www.ieagreen.org.uk/prghgt42.htm.)

[21] Cited in *Environmental Building News*, Vol 2 (2) 1993. See http://www.p2pays.org/ref/10/09944.htm

Figure 8: Wind turbine base at Cefn Croes, Wales, showing steel reinforcing bars and collar in place prior to pouring concrete. Note the 2m deep peat cut through at the rear.

Of course, cement is not the same as concrete. The cement content of high-strength concrete is variable depending on whether any fly ash is added, but a reasonable figure would be 12%. The other constituents would be sand and crushed stone in the proportion of 35% and 45% respectively – the balance being water. Based on the primary energy used to quarry sand and rock from the ground and transport it, it appears that the CO_2 debt of these materials is about one-tenth of the weight of the aggregate used by weight.

Thus, for a single turbine, the 120 tonnes of cement (12% of the 1,000 tonnes of concrete in the base) will generate around 96 tonnes of CO_2 (120 X 0.8) while the 880 tonnes of sand and aggregate will add a further 88 tonnes giving a total of 184 tonnes. In addition, steel manufacture releases about 2 tonnes of CO_2 per tonne,[22] or 64 tonnes per turbine, giving a total of 248 tonnes of CO_2 per turbine base.

Also important is the crushed rock used for the tracks, infilling the hole around the turbine base plus a covering layer over the concrete base. Tracks are typically 5 metres wide and at least 0.5 metres thick so our 'model' half-kilometre will require about 1,250 cubic metres of crushed rock or 2,500 tonnes (2 tonnes/m^3). As the CO_2 emissions here are about one-tenth of that of cement manufacture, this will add a further 250 tonnes of CO_2, whilst in-fill and covering will add a further 500m^3 (1,000 tonnes by weight), adding a further 100 tonnes of CO_2.

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[22] About 2 tonnes of CO_2 is produced per tonne of steel manufactured. See http://www.azom.com/news.asp?newsID=2530

Hence, the total CO_2 cost arising from construction activities for one 2 MW turbine with a half a kilometre of access track would be about 248 + 250 + 100tonnes, a total of 598 tonnes.

3.4 Release of stored carbon dioxide through peat disruption

If a bog system is disturbed, for example by hydrological change (mainly drainage to permit sheep grazing), repeated burning, excavation etc., then the breakdown, oxidation, and erosion of peat will release the stored carbon as CO_2. This process is likely to be rapid initially but once initiated will continue for many years at a slower rate.

Where a wind farm is proposed on a bog, developers argue that the disturbance will only take place where the tracks and turbines are built, plus a small area on either side. Also, applications often state that great care of peat will be taken, including its storage and later replacement, but no matter how well intended, this will not prevent oxidative breakdown once the hydrated status of the peat has been disrupted. It is also clear that many developers merely skim off the peat layer and spread it across uncut mire surface where it will rapidly decompose (see Figures 6 and 10).

In the case of the Isle of Lewis application, Scottish National Heritage and the developers agreed that 'collateral' damage 50 metres either side of the tracks and 50 metres around base excavations should be regarded as the area of potential damage.[23] This equates to the *medium scenario* used here though they did not use that term. Other studies[24] suggest that the damage can extend for as much as 200-250 metres either side of ditching and drainage excavations (Figure 9).

Figure 9: Peat drainage ditches at Cefn Croes wind farm, Wales which will lead ultimately to undercutting, slumping and the breakdown of peat for tens of metres either side of the ditches

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[23] Lewis Wind Farm Proposal, Environmental Statement, Vol.3, Section 11.1.4, p.4

[24] Lindsay R (2005), *Lewis wind farm proposal – observations on the official EIA*, p.47 and Table 3 p.49.

Whichever scenario applies, the loss of CO_2 from peat damage will be initially high and will continue at a lower level well beyond the life time of the wind farm. Irrespective of the scenario, the CO_2 loss from oxidising peat can be calculated using the parameters employed by Scottish Natural Heritage, namely:

- Solid content of peat is 10% (the remainder is water).
- Carbon content of dry peat is 49-62%, assume 55%.
- So carbon content of *in situ* peat is 55% X 10% = 5.5%.
- One cubic meter of wet peat weighs about 1 tonne (1,000 kg) so the carbon content is 55kg.
- Therefore carbon content of 1 hectare (= 1/100 of a square kilometre = 10,000m^2) of peat 1 metre deep = 10,000m^3 X 55kg = 550,000kg or 550 tonnes of carbon (which converts to 2017 tonnes CO_2). [25]

Low Scenario: It is now possible to calculate the CO_2 loss in the *low scenario* for our hypothetical wind farm assuming a mean peat depth of one metre. The area of damage for track, turbine base and hard standing is 14,150 m^2 (see p. 15) and thus the volume of peat at risk is 14,150 m^3.

- 14,150m^3 X 55kg = 778,250kg or 778 tonnes of carbon (X 3.67 = 2,855 tonnes CO_2).

Medium Scenario: In this scenario a half-kilometre track 5m wide (less 15% to allow for overlap) with a 60 metre band of collateral damage (50m + 10m) either side would, over time, release 10,720 tonnes of CO2. A single turbine base with a 50 metre zone of damage around a 20m X 20m base excavation would add a further 2,906 tonnes. The hard standing are likely to be within the areas of damage of the tracks and cannot be added into this or the *high scenario* but a conservative 500 tonnes could be included for borrow pits and other site works giving a total CO_2 debt of:

- 10,720 tonnes for track-associated damage;
- 2,906 tonnes for turbine base damage; and
- 500 tonnes assumed for damage due to borrow pits and other site works.

This more realistic calculation gives a greatly increased CO_2 debt over the *low scenario* of 14,126 tonnes. Although it may be spread over many years, it nevertheless has to be accrued on the debit side when considering the overall CO_2 payback time of a wind farm.

Hence the CO_2 released from our hypothetical wind farm due to peat damage will range from an absolute minimum of 2,855 tonnes for the *low scenario* to 14,126 tonnes for the *medium scenario*.

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[25] Scottish Natural Heritage, 'Technical Guidance Note', *Wind farms and Carbon Savings.* (June 2003), para 22.

High Scenario: However, Lindsay, in his detailed study of the Isle of Lewis site,[26] demonstrated that damage caused by a falling water table could cause peat breakdown for as much as 250 metres on either side of tracks or ditches. If this is so, peat oxidation may extend further and the figures could double or even treble. In this *high scenario* a band of collateral damage of 100m wide along the 25m wide track edge and 100m around turbine base holes is used. Here, the total debt will comprise:

- 15,895 tonnes for track-associated damage (0.5 km less 30% to allow for overlap);
- 9,769 tonnes for turbine base damage;
- 500 tonnes assumed for damage due to borrow pits and other site works.

Thus the total CO_2 debt due to peat damage for the *high scenario* is 26,164 tonnes.

Figure 10 : Derrybrien, Co. Galway. Tracks, turbine bases on the left of the main track, ditches, cable trenches, dumped peat and clear felling, all contribute to peat damage and CO_2 release.

4 Calculating the total carbon dioxide cost of a wind farm

By summating the CO_2 cost incurred in the previous four sections, the total debt for a one turbine wind farm with a half-kilometre track on one metre deep peat bed can be estimated as follows:

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[26] Lindsay R (2005). *Lewis wind farm proposal – observations on the official EIA*, p.47 and Table 3 p.49.

a) loss of CO_2 fixation by bog over 25 years = 25 tonnes
b) turbine fabrication, shipping and freighting (0.86t/MWh) = 2,378 tonnes
c) concrete and on-site construction = 598 tonnes
d) *low scenario* from peat damage = 2,855 tonnes
e) *medium scenario* from peat damage = 14,126 tonnes
f) *high scenario* from peat damage = 26,164 tonnes

Hence the **total** immediate and accrued CO_2 debt is:

- Basal Scenario (25m swathe of track damage) 5,856 tonnes [a+b+c+d]
- Minimal Scenario (25m track +50m collateral damage) 17,127 tonnes [a+b+c+e]
- High Scenario (25m track + 100m collateral damage) 29,165 tonnes [a+b+c+f]

These figures show that the major carbon dioxide debt incurred by a wind turbine on a peat-rich site is not in its manufacture and installation but in the ongoing degradation of peat. None of the papers from the wind industry dealing with payback have acknowledged this major source of atmospheric contamination.

5 Calculating the carbon dioxide ‘saved’ by a wind turbine

The CO_2 claimed to be ‘saved’ by the operation of the wind turbine by displacing emissions from fossil fuel power stations can be calculated from the method given in Annex 18A of the Isle of Lewis Wind farm Application (SNH Carbon Savings Guidance Note).[27] They state that CO_2 savings of 0.78 tonnes CO_2/MWh will result if the wind replaces only coal-fired power stations and 0.43 tonnes CO_2/MWh for the Grid average (this last figure is also that used by DEFRA, Ofgem and the DTI in England).[28] The BWEA and many wind power companies use a figure of 0.86 tonnes/MWh though this practice is changing slowly as they recognise the invalidity of their calculations. Here, a figure of 0.43 tonnes/MWh has been used, as it is in line with Government departments. It has also been supported in a recent ruling by the Advertising Standards Authority[29] which confirms that lifetime savings calculation should, at present, use this figure.

Thus a turbine of 2 MW installed capacity with a load factor of 30% (the value most often claimed in planning applications in the UK) will generate 5,256 MWh of electricity annually and the carbon dioxide savings would be 2,260 tonnes (2 x 8760 hrs x 30% MWh

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[27] SNH Carbon Savings Guidance Note, *Wind farms and Carbon Savings*. Lewis Wind Farm Proposal Appendix 18A, June 2003.

[28] The DTI Fact Sheet 14 states that the ‘energy mix’ should be used and not just displacement of coal generation. DEFRA and the Carbon Trust both use a figure of 0.43 t/MWh. Ofgem uses a figure of 0.43 t/MWh to convert Renewable Obligation Certificates into Emissions Trading Scheme Credits.

[29] ASA ruling on claims by Renewable Energy Systems Ltd, 21st December 2005, following an investigation by the Independent Reviewer of the ASA.

x 0.43)**.** Corresponding savings for load factors of 26.8% (the UK average for 2001-2004 inclusive) and 20% (the Danish average) would be 2,019 and 1,507 tonnes respectively.

6 Calculating the payback time for a wind turbine

It is possible to calculate for the hypothetical wind farm (one 2 MW wind turbine + a half kilometre track) the years needed to pay back its immediate carbon debt arising plus that from peat degradation over its lifetime. The results for the three scenarios for three load factors are shown below (Table 1). They are arrived at by dividing the CO_2 cost (see p. 22) by the claimed savings per year.

Table 1: Effect of load factor on the CO_2 payback time for 2 MW wind turbine for the Low, Medium and High scenarios of peat damage.

	Carbon dioxide cost (tonnes)	Payback time (years) @ load factors of		
		30% [a]	26.8% [b]	20% [c]
Low scenario	5,856	2.6	2.9	3.9
Medium scenario	17,127	7.6	8.5	11.4
High scenario	29,165	12.9	14.4	19.4

a = most frequently claimed LF in wind farm applications in the UK; b = average LF in the UK for 2001-2004; c = Long term Danish LF. Calculations assume a saving of 0.43t/MWh by displacement of fossil fuel.

In addition to load factor, several other variables can affect the payback times. One is the installed capacity of the wind turbine and another is the peat depth. Recalculated payback times for four sizes of turbine are shown in Table 2: the larger the turbine, the quicker the pay back.

Table 2: Effect of wind turbine installed capacity on payback of CO_2 debt for the low, medium and high scenarios at a 30% load factor

	Carbon dioxide cost (tonnes)[a]	Payback time (years) for four sizes of turbine with installed capacity of:			
		3MW	2.5MW	2MW	1.5MW
Low scenario	5,856	1.7	2.1	2.6	3.4
Medium scenario	17,127	5.0	6.1	7.6	10.1
High scenario	29,165	8.6	10.3	12.9	17.2

a = Small differences in CO_2 debt for manufacturing turbines of different size would affect the tonnages in this table but as they are minor they have been ignored.

The three ‘scenarios’ described here use a peat depth of 1 metre. However, it will be self-evident that the payback time will increase if the mean depth is greater than this, and vice versa (Table 3).

Table 3: Effect of peat depth on years of payback of CO_2 cost for a 2 MW turbine with 0.5km track for the low and medium scenarios

Scenario	Mean peat depth (m)	Total CO_2 cost (tonnes)[a]	Payback time (years) for a 2MW turbine
Low Scenario	2	8,713	3.8
	1.5	7,285	3.2
	1	5,856	2.6
	0.75	5,143	2.2
	0.5	4,429	2.0
	0.25	3,715	1.6
Medium Scenario	2	30,659	13.5
	1.5	23,444	10.4
	1	17,127	7.6
	0.75	13,223	5.8
	0.5	9,815	4.3
	0.25	6,408	2.8

a = CO_2 emissions from peat, fabrication and construction + fixation losses

Repeating this calculation for a site with deep peat (2 metres) the payback time for a 2MW turbine in the high scenario setting (100m damage round tracks and bases) would be longer than the 25-year lifetime of the wind farm, and no CO_2 savings would result.

In some respects, these payback times are understated because Government Departments (DEFRA)[30] are now using an even lower working figure for the expected CO_2 savings by 2010 of just 0.27 t/MWh for **all** renewables. This was confirmed in a written answer to the House of Commons by the then Energy Minister.[31] As 75% of renewables are supposed to be wind, the 2010 figure is likely to be between 0.43 and 0.27, probably in the region of 0.31 t/MWh, which is roughly what might be expected of new gas generation. This is very similar to the figure used by the Sustainable Energy Commission[32] for 2020 (97 tonnes carbon/GWh which translates to 0.36 tonnes of CO_2/MWh).

If these future rates of CO_2 saving are applied to the annual electricity generation figures above, the payback times in Table 1, 2 and 3 become even longer. In fact it is quite probable that in some cases there is no CO_2 saving at all, thus eliminating one of the main reasons for constructing wind farms in the first place.

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[30] DEFRA. Review of the Climate Change Programme, p. 42 para 6.9 and footnote 17. Savings expected are 2.5 million tones of carbon = 9.17mtCO_2. Divide this by the expected generation from renewable [33.6 terawatt hours] give a saving per MWh of 0.27 tonnes.

[31] O'Brien M, HoC Hansard Written Answers, 2nd February 2005, column 929W.

[32] *Wind Power in the UK*. Sustainable Development Commission, Section 4.5, page 35.

7 The cost of carbon dioxide abatement

Another principal issue arising from these payback times is economic. Given a range of emissions abatement techniques, it is obviously sensible to adopt those that deliver the best value for money. This is particularly important since the UK's role in international efforts to tackle climate change is not so much quantitative as qualitative. As noted above, the UK produces a bare two per cent of global emissions, and this proportion is falling due to very large growth in the developing world. China is currently about five times the size of the UK electrically, but is expected by 2020 to be between 20 and 30 times as large, consuming approximately 11,000 terawatt hours per year. A very large part of this will be generated from coal and gas. It is therefore incumbent on the UK to offer an economically compelling example of low carbon generation.

Renewable electricity, of any kind, is an expensive means of reducing emissions, a fact which has drawn comment from the National Audit Office. The payback times for wind turbines further increase this cost, and while precise quantification is complex, due to variability of load factor, uncertainties with regard to displacement, and indeed plant life (the wind industry routinely quotes 25 years, but in practice the actual achievable life for large rotating plant is unlikely to be much more than ten years). Granting these uncertainties, it is clear that a payback time of between 3 and 17 years in a lifetime of 10-25 years will have a very serious effect on the cost per tonne of CO_2 saved. Significantly, should wind farms be dismantled or the policy abandoned in the future, CO_2 emissions arising from peat damage will continue, as the process is largely irreversible.

8 Discussion

The payback time of the CO_2 liberated in the manufacturing and deployment of wind turbines has been a contentious issue for some years. To counter this, various papers have been published by individuals associated with the wind industry in an attempt to provide counter-arguments (see footnotes 18 and 19). On the whole these have been reasonable endeavours and have shown that payback time for these activities ranges from 6 to 30 months. Milborrow even makes the point that the payback time of nuclear and fossil fuel plants is also only a matter of months, reflecting their high electricity output that quickly offsets the greater CO_2 cost of their erection. However, the papers on wind turbines have not taken account of the loss of CO_2 fixation by damaged bog surface, the felling of forests or the accrued cost in CO_2 terms of the destruction of peat beds. This is unique to wind farms as they have an enormous footprint and are often constructed, unlike conventional power stations, in environmentally sensitive areas.

The Danish study by Krohn (from 1997) suggests that early wind turbines had an energy payback period of 8 months but that this had fallen to two to three months with what were then 'modern' machines. Clearly these figures will depend on the wind speed and efficiency of the particular turbine. The figures may be unduly low, as much energy in Denmark comes from Norwegian or other hydroelectric sources with 'zero' CO_2 emissions, and from interconnectors with other countries where renewable sources are available.[33] They also relate to a country with a home-grown turbine construction industry, and Krohn utilises the average energy demand for steel manufacture thus ignoring the energy intensive nature of modern wind turbine construction. In addition, Krohn has made no allowance for the carbon debt arising from the necessary upgrading or extension of their national grid, or that arising from the efficiency penalty imposed on conventional power stations running in standby mode to support wind power's variable generation. Notably, a 2% decrease in the efficiency of a coal-fired power station can add 10% to its carbon emissions.[34]

With regards to the loss of new carbon fixation, the data discussed here show it to be insignificant in terms of national emissions (550 million tonnes per year in the UK). Even if 25,000 2MW turbines were built on peat-rich sites the loss of CO_2 fixation would be only about 0.1% of UK annual emissions. This same conclusion was reached by Scottish Natural Heritage[35] in calculations based on a 10 MW wind farm on a 260 hectare site where they state, *'The loss of the carbon-fixation capacity of a bog on which a wind farm is build is thus not significant in relation to the carbon emissions which the wind farm will 'save' through the non-use of fossil fuels'.* Though not specifically addressed here, the clear felling of forests on upland sites, which is necessary to allow a smooth airflow to wind turbines in such areas, could have a higher direct CO_2 cost in addition to exposing vast tracts of damaged, ploughed peat to further oxidation.

Of greatest concern must be the damage to peat beds that occur through the excavation and drainage works conducted to install upland wind farms. Planning applications often state that a wind farm only occupies one to two per cent of a site area. While true in the strict spatial sense the statement entirely fails to take account of the collateral damage to adjacent peat beds caused by such activities.

This point is acknowledged in the agreement between Scottish National Heritage and AMEC/British Energy, the developers of the Isle of Lewis wind farm to use a band of 50m on either side of the tracks to calculate the extent of potential peat damage. Although, this choice of width is not supported by any scientific rationale, it has been adopted here for the *medium scenario* as it reflects at least one example of current practice by a statutory body.

However, evidence supports the view that potential peat damage can extend well beyond 50 metres. In a detailed assessment of the Lewis peatland site, Lindsay[36] clearly

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[33] Sharman H, 'Why Wind Power Works for Denmark'*, Civil Engineering*, V.158 (2), p66-72.

[34] Siemens Industries chart reproduced in *Science in Parliament, 60/2* (Whitsun 2003).

[35] Scottish Natural Heritage, 'Technical Guidance Note', *Wind farms and Carbon Savings.* (June 2003).

[36] Lindsay R (2005), *Lewis wind farm proposal – observations on the official EIA.*

demonstrates the extent to which the developer had under-estimated the potential damage: Rather than the 189.9 hectares of active blanket bog at risk the true figure is estimated to be 30 times higher (6,255 hectares).

Lindsay also re-analyses other studies which show that ditching, drainage and road works can cause a lowering of the water table for as much as 250 metres from the workings. At this distance the effect does not appear very great (5-10cm at 200 metres distance) but is enough to cause the drying of the acrotelm and the oxidation of the surface peat layer. This is then scoured away by rain and wind to expose the catotelm peat with a further fall in the water table. Such gradual cumulative losses can reduce the height of peat banks by many metres, as at Holme Fen Post in Cambridgeshire where Lindsay states, *'…the peat has been drying for 150 years. In this time it has lost a depth of 5 metres – a rate of more than 3cm per year…'*. Hence, collateral effects are likely to be more widespread, with greater long-term damage than is superficially evident on the surface. This raises serious doubts about the wisdom of constructing wind farms on peat-rich sites at all, especially as such sites are often legally protected under EC Habitats Directives.

It is significant that the UK Government fully accepts the scale of these effects of peat degradation on hydrological and sequestration grounds and has referred this issue to the Office of the Deputy Prime Minister.[37]

In practice, there may be topographical considerations which reduce the extent of damage to less than 200-250 metres. For example, undulations which affect peat thickness, or the presence of small rocky knolls that interrupt the peat bed. For that reason, this paper has chosen an intermediate width of 100 metres for its *high scenario*.

Quite apart from the damage caused to peat by construction and drainage, there are many other negative impacts caused by wind farms on blanket bogs. These include interference with natural drainage patterns, mineralization of down-slope areas, drying of down-slope peat caused by tracks built on sloping terrain, siltation and peat slides. All but the last of these impacts have been apparent at the site of Cefn Croes wind farm (Wales) where the draining of a large area of raised bog in order to keep the turbine bases dry has resulted in widespread degradation of the mire surface, breakdown of sub-surface peat, siltation of becks and rivers, and the creation of a landscape best described as one of desolation (Figure 11).[38] Though a peat slide has not occurred at Cefn Croes they are fairly common on disturbed blanket bog. The worst example has been that at Derrybrien where an estimated half-million tonnes of peat slid down the hillside in October 2003 during the construction of a wind farm. This will degrade to liberate over 100,000 tonnes of CO_2.

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[37] Letter from Secretary of State, Margaret Beckett to William Hague MP following correspondence with Yorkshire CPRE, Summer 2004.

[38] Minutes of the Cefn Croes Wind Farm Environment Management Committee, 23rd February 2005, para 4.

Figure 11: Deforested, drained and damaged wilderness at the site of turbine 25, Cefn Croes

Although a lesser consideration, the cost per tonne of CO_2 saved by wind power is likely to be significantly increased by even the shorter of the above payback times and wind power, in common with other renewable technologies, is already acknowledged to be a very expensive means of reducing emissions.[39] In practical terms the situation is even worse, as no account has been taken of the CO_2 cost of strengthening the grid, the lowered efficiency of running fossil fuel plants at reduced output, or ongoing cost of repairs and maintenance. More cost-effective measures are clearly needed.

In conclusion, it is clear that the collateral damage caused by wind farm construction on peat-rich sites is more widespread and produces greater long-term damage than is superficially evident. Many Public Inquiries now cite climate change (and thus the need for CO_2 abatement) as the major reason for granting planning permission for wind farms against the wishes of local authorities. This paper clearly demonstrates that this rationale is flawed, as CO_2 emissions may be considerably higher than often stated, thus greatly reducing the value of wind power in contributing to CO_2 reduction targets. It even questions the wisdom of constructing wind farms at all on peat rich sites which are both national and internationally protected habitats.

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[39] House of Commons Committee of Public Accounts. *DTI: Renewable Energy.* Sixth Report of Session 2005-2006, September 15th 2005, Ref HC 413.

APPENDIX: Calculating the carbon dioxide cost and the payback time of a specific wind farm (manual method)

[Note: The payback time for any given wind farm can be calculated most easily and automatically from an Excel spreadsheet developed jointly by REF and the Scottish Wind Assessment Group. A short explanatory Guide can be downloaded from ***www.ref.org.uk*** *or* ***www.swap.org.uk*** *and a copy of the spreadsheet can be requested from the Renewable Energy Foundation by e-mailing* ***peat@ref.org.uk****.]*

The following information is needed. Some of it varies from site to site but other figures are constants.

Site-dependent factors are:

- The number and installed capacity of the turbines
- The claimed load (or capacity) factor (expected annual output as a percentage of the maximum possible)
- The size of the turbine bases, hard standings and quarries (‘borrow pits’)
- The total length, width and depth of the aggregate laid for the access tracks
- The width of any drainage ditches cut alongside the access tracks
- The average depth of peat on the site

All the above should be available from the Environmental Statement. Factors applicable to all sites are:

- The hours in a year (8760)
- The carbon fixed by a growing bog (19 gm/m^2/year)
- The conversion factor, carbon to CO_2 (multiply carbon by 3.67)
- The CO_2 released during turbine manufacture (1,189t CO_2/MW of turbine capacity)
- The CO_2 displaced at a power station by wind-power generation (0.43tCO_2/MWh)
- The CO_2 released per 15m x 15m x 1.5m turbine base (248 tonnes/base). (Includes cement, aggregate, rock, steel, and sand
- The CO_2 emitted by quarrying and crushing rock (0.2 tonnes/m^3)
- The weight of peat (one t/m^3) and the carbon content of dry peat (55kg/m^3)

A worked example:
Calculating CO_2 payback time for the Whinash wind farm

The Whinash site, which was rejected in March 2006 following a Public Inquiry, would have occupied a rounded ridge between the Lake District and Yorkshire Dales National Parks. The total area of 763 hectares is composed of blanket bog in relatively poor condition, purple moor grass/rush pastures and upland heath. Compared to many sites in Wales and Scotland, it has a shallow peat covering and patchy blanket bog. It is deemed to be a *medium scenario* site and the extent of peat degradation is thus assumed to be 50 metres. The data below are taken from the Planning Application, the Environmental Statement and a separate volume of Supplementary Environmental Information.

Number of turbines = 27
Installed capacity of each turbine = 2.5 MW
Total installed capacity = 27 x 2.5 = 67.5 MW
Claimed load factor = 35%
Electricity generated = 67.5 x 8,760 hours/year x 35% = 206,955 MWh/annum
CO_2 ‘saving’ = 206,955 x 0.43 t/MWh = 88,990 tonnes/annum
Access tracks = 16.7 km long x 5 metres wide x 0.5 metres deep
Average peat depth = 0.48 metres (rounded to 0.5m)
Site life = 25 years

How much CO_2 would be emitted?

CO_2 emitted during fabrication and assembly of turbines

CO_2 emitted = 1,189t/MW x 27 x 2.5 = 80,258 tonnes

CO_2 emitted during manufacture of the turbine bases

CO_2 emitted = 248 tCO_2/base x 27 = 6,696 tonnes

CO_2 emitted by quarrying and crushing aggregates for access tracks and turbine bases

Volume of access tracks = 16,700 m x 5 m x 0.5 m = 41,750 m^3
Volume of base ballast = 500m^3/base x 27 = 13,500 m^3
Volume of hard standings = 50 m x 20 m x 0.5 m x 27 = 13,500 m^3
Thus total aggregate volume = 41,750 + 13,500 + 13,500 = 68,750 m^3
And CO_2 emitted = 68,750 x 0.2 tCO_2/m^3 = 13,750 tonnes

CO_2 emitted due to loss of fixation by damaged bog

The *low scenario* is always used to calculate fixation loss. The area of bog surface is as follows:

Weighted track length = 16,700m less 2% = 16,366m
area damaged by access tracks = 16,366m x 25m = 409,150 m^2 (25m comprises 10m damage + 5m track + 10m damage)
area damaged by turbine bases = 27 x $(5 + 20 + 5)^2$ = 24,300 m^2
area damaged by hard standings = 50 x 20 x 27 = 27,000 m^2
area damaged by borrow pits = NIL (off-site quarries proposed for Whinash)
thus TOTAL area damaged = 409,150 + 24,300 + 27,000 + 0 = 460,450 m^2
lost annual sequestration = 460,450 x 19gm/m^2/year = 8.75 tonnes carbon
lost site lifetime due to sequestration = 8.75 x 25 years = ~220 tonnes
thus fixation loss = 220 x 3.67 = 808 tonnes CO_2

CO_2 emitted by peat oxidation over time

Weighted track length (medium scenario) = 16,700 less 15% = 14,195 m
Peat damaged by access track construction = (14,195 x (50 + 25 + 50)) x 0.5 = 887,187 m^3
Peat damaged by turbine base construction = $(50 + 20 + 50)^2$ x 0.5 x 27 = 194,400 m^3
Peat damaged by 'borrow' pits = zero (off-site quarries proposed for Whinash)
Total volume of damaged peat = 887,187 + 194,400 + 0 = 1,081,587 m^3
Thus CO_2 emitted = 1,081,587 x 55kgC/m^3 x 3.67 =
218,317 tonnes

Total site CO_2 cost

Emitted by turbine fabrication = 80,258
Emitted by concrete manufacture = 6,696
Emitted by aggregate extraction = 13,750
Loss due to fixation = 808
Emitted by peat oxidation = 218,317
Total emissions = 318,779 tonnes

What is the payback time?

Payback time = 318,779 ÷ 88,900 tCO_2 displaced/year
= ~3.6 years

Note 1. no deforestation would have been necessary at Whinash.

Note 2. The CO_2 emissions from peat oxidation above (318,779 tonnes) differ slightly from the figure obtained with the spreadsheet (311,075) due to a slight difference in the method of calculation. This has no significant effect on the end result.

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