SCOTTISH
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Guidance

Technical Guidance Note

Windfarms and Carbon Savings

This note discusses the likely carbon-savings associated with windfarm developments on areas of blanket bog and forests.

Summary

Assuming windfarms displace electricity generated by coal-fired generation, then they 'pay' for any carbon loss through development on peat or in forests in 1-2 years. If it is the overall grid mix that is displaced, then the payback time is 1-3 years. In spite of the simplifications and assumptions that are necessary in these calculations, the estimates indicate that in most cases windfarms will 'pay' for themselves within 3 years. The payback period could however be much longer (20-30 years) if the design of the windfarm on peatland were such as to allow wholesale degradation of the peat, and in such cases the loss of stored carbon and long-term carbon-fixing potential could be a concern.

Contents

Introduction

1. SNH's policy statement 01/02 on Renewable Energy makes clear SNH's support for renewable developments, provided that this is associated with efforts to enhance energy efficiency and reduce the overall demand for energy, as part of the UK Climate Change Programme. This is to ensure that renewable developments make a genuine contribution to reducing greenhouse gas emissions rather than soaking up new energy demand.

2. SNH has supported the Scottish Executive's target of achieving 18% of electricity generation from renewable sources by 2010, and for that target to be increased to 40% by 2020. These targets include the existing 10% contribution to electricity supply from large-scale hydro. SNH urges that the renewable mix should be diverse, exploiting the potential of offshore wind, wave and tidal resources as well as onshore wind.

3. Any attempt to meet a 40% target relying predominantly on onshore wind could result in increasingly difficult trade-offs with the natural heritage, especially landscape interests. Indeed such conflicts of interest inform many current local campaigns against specific windfarm development proposals. One argument that is sometimes mooted against windfarm developments is based on the likely overall carbon-savings associated with developments in forests or on blanket bog. This is the focus of the current Note.

Background

4. Scotland has extensive carbon-rich (peat-based) soils which can act as carbon-sinks or carbon-sources depending on how they are managed. In 1999 it was estimated that 20% of Scotland's annual CO_2 emissions were from land use change and forestry[1]. Experience to date is that it is exceedingly difficult to quantify in detail carbon cycling between vegetation, soils, and the atmosphere[2] and this is increasingly difficult for larger areas and longer timescales. However, in general undisturbed soils are more likely to act as sinks than sources, and at a global level wetlands (including bogs) store over 3 times as much carbon *for a given area* as tropical rainforest[3].

5. This Note provides a methodology to explore whether, overall, a windfarm development is likely to represent a carbon-saving or carbon-cost. It discusses the likely carbon-savings or carbon-costs associated with windfarm developments as follows:

   i. carbon emission savings (based on emissions from different generating sources)
   ii. loss of carbon-fixing potential on bogs
   iii. loss of carbon stored on bogs
   iv. loss of carbon-fixing potential as a result of woodland clearance

6. Because of the uncertainties involved in estimating the relevant carbon-budgets, it will only be possible to give a general indication of the likely balance. Thus, if the pay-back time is within 5 years over a 20-25 year project one can be comfortable that there is likely to be an overall carbon-saving, but if the payback time approaches say 15 years then it may be worth studying the carbon budgets more rigorously, or questioning whether the project is justified on the basis of climate change benefits.

7. The note does not cover some wider issues, which may be significant if the estimated pay-back time approaches say 15 years. These issues include the need to maintain supply from other sources (including fossil fuel sources) on still days. The note assumes that the emissions per unit from back-up sources before and after the windfarm development are unaffected by the windfarm – this factor is allowed for in the assumption of a 40% utilisation rate (paragraph 13) and the likelihood of sufficient slack in the overall grid supply so that the back-up mix of fuel sources remains unchanged. The calculations also exclude off-site carbon costs, for example, associated with the erection of transmission lines.

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[1] Key Scottish Environment Statistics, p.14

[2] e.g. Review of the Contribution to Climate Change of Organic Soils under Different Land Uses, Scottish Executive Environment Group Research Programme Research Findings No. 17

[3] This is because of the large amount of carbon stored in the soil. Note that overall tropical rainforest is a larger carbon sink than wetland, because there is so much more tropical rainforest than wetland. The Royal Society, 2001, p.3

Carbon emission savings

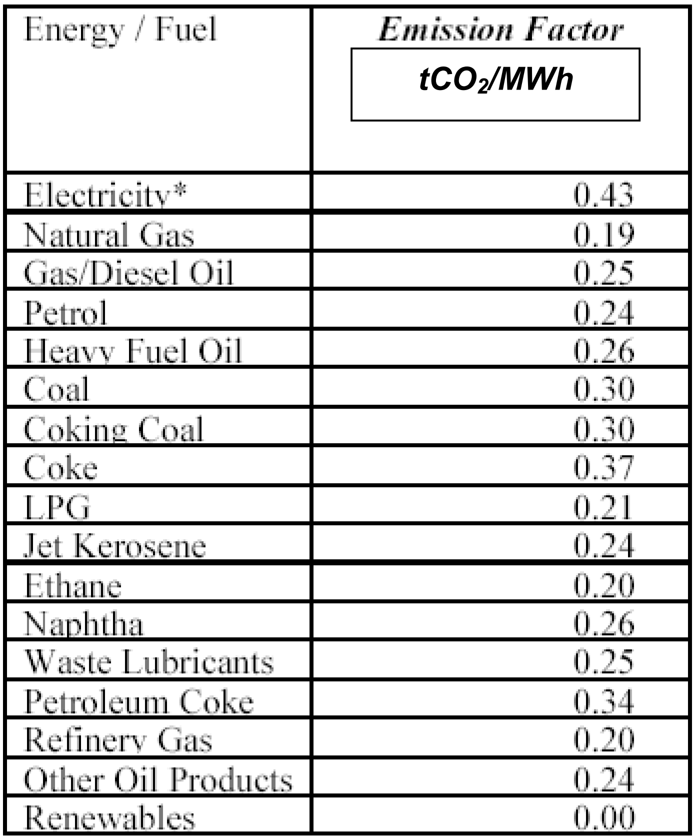
8. Emissions may be quoted in terms of tonnes of CO_2 or tonnes of C. The conversion figures are:

   1 tonne C = 3.66tCO_2
   1 tCO_2 = 0.27tC

9. Authoritative figures for calculating emissions from various sources, including power stations, are given by the Guidelines for the Measurement and Reporting of Emissions by Direct Participants in the UK Emissions Trading Scheme (DEFRA, Oct 2002). Worked examples, including one for the carbon saved by generating electricity from wind energy as opposed to the conventional mix (including fossil fuel sources), are given by The Carbon Trust website.

Carbon emissions from electricity generation

10. Carbon emissions from energy production depend on the fuel used, as shown in Table 1[4].



Energy / Fuel	*Emission Factor* ***tCO_2/MWh***
Electricity*	0.43
Natural Gas	0.19
Gas/Diesel Oil	0.25
Petrol	0.24
Heavy Fuel Oil	0.26
Coal	0.30
Coking Coal	0.30
Coke	0.37
LPG	0.21
Jet Kerosene	0.24
Ethane	0.20
Naphtha	0.26
Waste Lubricants	0.25
Petroleum Coke	0.34
Refinery Gas	0.20
Other Oil Products	0.24
Renewables	0.00

Table 1. CO_2 emission factors for energy-related emissions[6]. *A common emission factor is used for all electricity supplied from public supply network. This emission factor does not vary from year to year.

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[4] From p. 20 Guidelines for the Measurement and Reporting of Emissions by Direct Participants in the UK Emissions Trading Scheme (DEFRA, Oct 2002)

[5] From p. 20 Guidelines for the Measurement and Reporting of Emissions by Direct Participants in the UK Emissions Trading Scheme (DEFRA, Oct 2002)

11. These emission factors do vary, for example with technological advances: the figures quoted here are 'fixed' for simplicity and are those used in the UK Emission Trading Scheme. However, all of them, except the average electricity emission factor (see below) do need to be multiplied by a figure of 2.6, to allow for inefficiencies in the transformation process, mainly due to heat loss[7] (2.6 factor assumes 38.5% efficiency[8]). The resulting emission factor for coal is 0.78 tCO_2/MWh (2.6 x 0.30 tCO_2/MWh). The average electricity emission factor, taken across the mix of electricity sources supplying the UK grid as a whole, is 0.43 tCO_2/MWh – this figure already takes account of inefficiencies in generation from fossil fuel sources, so does not need to be multiplied by 2.6.

Windfarm carbon emission savings

12. This Note follows the example given by The Carbon Trust[9], adapted for coal-fired generation and the overall generating mix. A renewable energy development will have maximum potential to 'save' carbon emissions if it substitutes for generation from coal-fired generation. However, in most circumstances it is not possible to define the electricity source for which a renewable electricity project will substitute. The calculations in this Note therefore include two sets of figures – one set based on substitution for coal-generated electricity, and one based on substitution for the grid-mix (paragraphs 15, 16, and detailed in Annex A)

13. Estimates of carbon emission savings are made for two example windfarms, with generating capacities of 10MW[10] and 240MW[11]. These capacities are assumed to facilitate comparison with the examples used in the later sections of this note. The utilisation rate assumed is 0.4 (i.e. the overall yield of turbines is 40% of their rated generation capacity – this allows for maintenance and windless days – in line with wind industry figures).

14. The emissions savings are estimated by multiplying the total annual electrical output by the emission factor for the generation substituted (coal-fired generation and average UK grid mix) – see Annex A for calculations.

15. Example 1, 10MW case

	Coal-fired	**Grid mix**

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[6] Figures in the original table are expressed in $kgCO_2$/kWh: here they are scaled up to tCO_2/MWh – so the figures are numerically identical, but the presentation here simplifies the calculations in Annex A, and is better suited to the likely scale of wind energy developments.

[7] Electricity is not a primary fuel, but a means of transporting energy from the point of generation to the point of use. Overall emissions from electricity generation depend not only on the primary fuel used, but also on the efficiency of conversion: for most systems, much of the energy is dissipated as heat at the power station. Among fossil fuels, natural gas is relatively 'clean', followed by oil with coal being the most polluting in terms of carbon emissions. Electricity generated from renewable sources is zero-rated, as is electricity from nuclear sources. (For renewables there are carbon emissions associated with the building of turbines, concrete foundations, servicing and maintenance, and these may be relevant when examining marginal cases (as discussed in paragraphs 6-7. Emission factors for production of concrete are given on p.29 of the Defra guidelines). Similarly for nuclear sources there are carbon emissions associated with the building and decommissioning of plant, and the winning, processing and transportation of fuel.)

[8] DEFRA (2001) Climate Change Agreements: Guidance on converting electricity from dedicated supplies to primary energy. CCA 09, December 2001

[9] The Carbon Trust example 2, electricity generation

[10] A proposed 10MW windfarm on blanket bog at Melvich

[11] A proposed 240MW windfarm requiring clearance of 1000 ha of forest, Whitelee

Carbon expressed as tC	7379 tC/yr	4,068 tC/yr
Carbon expressed as tCO_2	27,331 tCO_2/yr[12]	15,067 tCO_2/yr

16. Example 2, 240MW case

	Coal-fired	**Grid mix**
Carbon expressed as tC	177,106 tC/yr	97,635 tC/yr
Carbon expressed as tCO_2	655,949 tCO_2/yr	361,613 tCO_2/yr

Land Carbon Sinks

17. Given the difficulties of reducing energy use and associated greenhouse gas emissions, attention has been diverted to the possibility that naturally occurring ‘carbon sinks’ for CO_2 on land and in the oceans might be manipulated to provide enhanced uptake of this greenhouse gas into biological systems. The most important mechanism for this uptake in both terrestrial and aquatic environments is the process of photosynthesis in which CO_2 is converted first to sugars and then to structural plant polymers such as cellulose and lignin. Since virtually all such carbon is eventually returned to the atmosphere in the process of respiration, fixation of this kind is essentially a temporary solution, but the period of carbon sequestration (i.e. uptake and storage) can be maximised by selection of crops and management regimes that provide the longest possible retention times. For this reason forests, in which much of the fixed carbon is retained for decades in tree wood and for centuries in soil organic matter, are natural candidates for possible enhancements of land carbon sinks. Uptake and storage of carbon by naturally functioning wetlands, especially bogs, is also important in this regard (paragraph 4). Two aspects are important, first the rate at which carbon is taken-up in live vegetation (carbon-fixation on bogs), and, second, its storage in soil organic matter (carbon-storage on bogs).

Loss of carbon-fixing potential on bogs

18. The amount of land taken by a windfarm development (e.g. the area of tracks, turbine bases) will reduce the amount of carbon that can be fixed in live vegetation. However, for bogs the amount of carbon fixed in live vegetation is quite small (the bulk of carbon is stored in soil), so the calculations here are based for simplicity on the ‘worst-case’ scenario of the carbon-fixation potential of the entire bog area being lost due to the windfarm development.

19. The case is based on a 10MW windfarm on a 260ha site: **carbon fixation** by bogs ~ 0.25tC/ha/yr, or 65tC/yr for a 260ha site.

    When compared with the carbon savings for the same 10MW windfarm indicated in paragraph 15, it would take 113 years (7379/65) for the site to fix the carbon that the windfarm will ‘save’ in 1 year (coal-fired generation), or 63 years (4068/65, grid-mix)[13]. **The loss of the carbon-fixation capacity of a bog on which a windfarm is built is thus not significant in relation to the carbon emissions which the windfarm will ‘save’ through non-use of fossil fuels.**

Loss of carbon stored on bogs

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[12] These figures are consistent with results of calculations given by The Carbon Trust (30,000tCO_2 per yr) and Melvich Windfarm 33,215 tCO_2 per yr for a 10MW case. In each case the total here for a 240MW case is about 24 times greater than the 10MW cases.

[13] The EIA uses an emissions factor of 0.949 $kgCO_2$/kWh, hence a saving of 33,215tCO_2 per year or 8968tC/yr and a time of 138 yr (8968/65)

20. As indicated above, the bulk of carbon associated with bogs is stored in the organic soil (peat). The long-term decomposition of bog vegetation is associated with uptake and release of carbon through various complex reactions involving carbon dioxide and methane. However, *if the bog system remains intact* the overall result is that carbon is effectively stored over the lifetime of the bog, extending to hundreds or thousands of years. If the bog system is disturbed, for example its hydrology, then the decay, oxidation, and erosion of peat will release the stored carbon.

21. The critical question is the extent to which the hydrology of the bog is affected by the windfarm development. Proponents of wind energy developments will tend to argue that the hydrology of the bog will only be affected over the area required for the infrastructure of the windfarm (e.g. track network and turbine bases). Others may argue that bog ecosystems are such that any development will result in the hydrology of the entire bog being affected – and lowland raised bogs are likely to be more sensitive in this regard than blanket bogs. Careful attention to the design and construction of the windfarm is required: if the infrastructure can in effect be ‘floated’ on the bog, then it is likely that the disturbance to the hydrology will be minimal, but deeper foundations are likely to have more adverse impacts[14]. The calculations here are based on carbon-loss over an area double that required for the infrastructure (5% of the site, assuming 2.5% required for infrastructure), and carbon-loss over the entire site.

22. Example: Windfarm situated on 260 Ha of peat 1.5m deep

    Moisture content of peat = 90 – 93%[15] – so assume 90%, i.e. 10% dry matter

    Carbon content of dry peat = 49-62% - so assume 55%

    So, carbon content of fresh (*in situ*) peat ≅ 55% x 10% = 5.5%

    And, carbon content of 1m^3 fresh peat (weighing ~ 1tonne) = 55kg

    Thus, carbon content of 1 ha of peat 1m deep = 550 tonnes

    If the peat averages 1.5m deep, then:

    carbon content of site = 550 x 1.5 x 260 = 214,500 tonnes

    annual carbon-saving of the windfarm = 7379tC (coal-generation) or 4068tC (grid mix)[16]

    If only 5% of the site were lost, then the windfarm would ‘pay’ for itself in 17.5 months (5% of 214,500/7379 for coal-fired generation as the counterfactual case) [17], rising to 31 months for the grid-mix counterfactual case. It would take 29 years (214,500/7379) for the windfarm to account for itself *if all* the peat on the site were lost (assuming coal-fired generation as the counterfactual case)[18]. This figure rises to 52 years using the grid-mix as the counterfactual case.

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[14] Careful assessment of EIAs may be required in this regard: some may be optimistic in terms of the load-bearing capacity of ‘floating’ infrastructure, which may subsequently require deeper foundations with consequent wider impacts on bog hydrology and carbon-loss. There is a growing body of best practice (e.g. from Ireland and increasingly Scotland) to inform our advice.

[15] Report by MLURI *et al* to Dept of Energy, 1991

[16] paragraph 15

[17] Using the applicants EIA figures would give 14.5 months

[18] The applicants EIA figures, using an emissions factor of 0.949 kgCO_2/kWh and a saving of 8968 tC/yr, give a figure of 24 years

23. If track and turbine infrastructure is designed to avoid disruption of the hydrology, a windfarm is likely to rapidly repay any loss of carbon storage from the disrupted peat. **However, a windfarm development *could* have a significant impact on carbon emissions through the release of carbon already stored within a bog, depending on the extent of disruption to the hydrological system beyond the direct impact of the works[19].**

Loss of carbon-fixing potential as a result of woodland clearance

24. Often it may be necessary to clear existing forestry or woodland in order to make way for a windfarm[20]. This may be to make space for tracks or turbines, or to avoid turbulence due to forest edges. The emission savings from the windfarm are offset by carbon losses, as the felled timber is likely to decay and ultimately convert to CO_2 emissions (paragraph 17). The amount of carbon loss depends on the type of tree, the age of the crop on felling, the end use of the timber and more generally how quickly any stored carbon is returned to the atmosphere (see e.g. Cannell, 1999).

25. Cannell (1999), provides estimates for the amounts of carbon sequestered by fast growing trees (circa 26 year rotation - e.g. poplar), medium growth (ca. 55 yr rotation - e.g. sitka spruce), and slow growth (ca. 92 yr rotation, e.g. beech)[21].

Poplar	**Sitka**	**Beech**
Yield class 12 m^3/ha/a	YC 16 m^3/ha/a	YC 6 m^3/ha/a
sequesters 7.3tC/ha/a	sequesters 3.6tC/ha/a	sequesters 2.4tC/ha/a
in 26yr gives	in 55 yr gives	in 92 yr
189.8tC/ha sequestered	198tC/ha sequestered	221tC/ha sequestered

26. Example:

A 240MW windfarm requires the clearance of 1000ha of sitka spruce forest.

Using the figures for sitka and assuming the forest is mature, this releases **198,000 tC (or 724,680 tCO_2)**. Thus the windfarm will 'pay' for itself in 1.1 years (198,000/177106, para 16) in the case of coal-fired generation, and in 2 years (198,000/97635) for the grid-mix.

27. In general, maximum carbon losses are likely if windfarms substitute for the more-productive commercial plantations and especially old growth natural or semi-natural woodlands in which up to 50% of the carbon could be stored in non-timber vegetation and organic soil[22]. However, land most likely to be favoured for windfarm development is likely to be occupied by commercial plantations of poor quality (in terms of productivity and carbon sequestration potential or biodiversity interest), which tend to be found at the higher altitudes favoured by windfarm developers. Thus, although the figures do not account for carbon stored in the woodland soil, they are based on more productive forest than is likely to be substituted for windfarm developments, so overall provide a reasonable estimate of the carbon-costs involved.

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[19] Loss of stored carbon, for example through erosion, will in turn reduce rates of carbon-fixation. Thus the figures here could underestimate the total carbon cost (carbon fixation costs *plus* carbon storage costs) by 5-10% (but this is more than allowed for in the discussion in paragraphs 28-31).

[20] A proposed 240MW windfarm requiring clearance of 1000 ha of forest, Whitelee

[21] These three woodland types are representative of fast-, medium-, and slow-growth trees – for more detail see Dewar and Cannell (1991)

[22] There are of course other natural heritage interests associated with native and semi-native woodland that would make clearance for windfarm developments highly undesirable

Implications for SNH

28. **Assuming windfarms displace electricity generated by coal-fired generation, then they 'pay' for any carbon loss through development on peat or in forests in 1-2 years. If it is the overall grid mix that is displaced, then the payback time is 1-3 years.**

29. These calculations are for simple cases, but are robust insofar that they follow the methodology for carbon accounting proposed by DEFRA in accordance with the UK Emissions Trading Scheme.

30. **Key variables** are the emission factors for fossil-fuel generation, the utilisation rate, and the wider hydrological impacts on bogs. DEFRA uses a 'middle-of-the-range' **emission factor** of 0.78 tCO_2/MWh, compared with 0.949 used by the wind industry and 0.5 by the Electricity Association). Figures for the **utilisation rate** range from 0.7 (The Carbon Trust) to 0.35-0.45 (wind industry) – and adversaries of wind energy might use more pessimistic figures. People arguing against wind energy developments on bogs might argue that carbon storage (and associated release) should be calculated on the basis that the **hydrology** of the entire site is affected, whereas advocates are likely to argue that only the area directly affected by the works should be considered: the figure of 5% used here allows for the hydrology to be affected over an area double the width of the access track. The wider hydrological impact of associated works may merit closer attention especially in cases where windfarm developments are proposed on intact areas of active bog. Any such study should also consider greenhouse gases other than CO_2, especially methane (CH_4).

31. **In spite of the simplifications and assumptions that are necessary in these calculations, the resulting estimates are useful in that they indicate in most cases windfarms will 'pay' for themselves within 3 years. SNH would be more concerned if the payback time was likely to be 10-15 years over a 20 year development.**

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Annex A – counterfactual cases – calculations

1. The total emissions savings are given by estimating the total possible electrical output of the technology multiplied the emission factor for the counterfactual case (coal-fired generation and electricity from the grid)

2. *Coal-fired case – emission factor 0.78 tCO_2/MWh*

   CO_2 emissions saving = total predicted electricity production from the windfarm (MWh) x emission factor (tCO_2/MWh)[23]

   Total predicted electricity production from windfarm = 240MW x number of hours of use (operating days (365 x utilisation rate (0.4) x 24))

   Total predicted electricity generation from windfarm = 840,960 MWh

   Emission saving (tonnes CO_2) = windfarm electricity generated (MWh) x emission factor (tCO_2/MWh)

   Emission saving (tonnes CO_2) = 840,960 MWh x 0.78

   Result

Total emission saving	240MW case	10MW case
Carbon expressed as tC	177,106 tC/yr[24]	7379 tC/yr
Carbon expressed as tCO_2	655,949 tCO_2/yr	27,331 tCO_2/yr

3. *Grid-based case – emission factor 0.43 tCO_2/MWh*

   Result

Total emission saving	240MW case	10MW case
Carbon expressed as tC	97,635 tC/yr	4,068 tC/yr
Carbon expressed as tCO_2	361,613 tCO_2/yr	15,067 tCO_2/yr

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[23] expressing the emission factor in tCO_2/MWh, and electricity production in MWh, removes the need for the conversion factor of 0.001 (to convert kg to tonne) shown in the method on The Carbon Trust website

[24] These figures are consistent with results of calculations given by The Carbon Trust (30,000tCO_2 per yr) and Melvich Windfarm 33,215 tCO_2 per yr for a 10MW case. So in each case the total here for a 240MW case is about 24 times greater than the 10MW cases.
