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Wind farms on undegraded peatlands are unlikely to reduce future carbon emissions

Jo Smith*, Dali Rani Nayak, Pete Smith

Institute of Biological & Environmental Science, University of Aberdeen, 23 St Machar Drive, Aberdeen AB24 3UU, UK

HIGHLIGHTS

- Future wind farms located on undegraded peats will not reduce carbon emissions.
- This is due to projected changes in fossil fuels used to generate electricity.
- Future policy should avoid constructing wind farms on undegraded peats.

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ABSTRACT

Onshore wind energy is a key component of the renewable energies used by governments to reduce carbon emissions from electricity production, but will carbon emissions be reduced when wind farms are located on carbon-rich peatands? Wind farms are often located in uplands because most are of low agricultural value, are distant from residential areas, and are windy. Many UK uplands are peatlands, with layers of accumulated peat that represent a large stock of soil carbon. When peatlands are drained for construction there is a higher risk of net carbon loss than for mineral soils. Previous work suggests that wind farms sited on peatlands can reduce net carbon emissions if strictly managed for maximum retention of carbon. Here we show that, whereas in 2010, most sites had potential to provide net carbon savings, by 2040 most sites will not reduce carbon emissions even with careful management. This is due to projected changes in the proportion of fossil fuels used to generate electricity. The results suggest future policy should avoid constructing wind farms on undegraded peatlands unless drainage of peat is minimal and the volume excavated in foundations can be significantly reduced compared to energy output.

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1. Introduction

Onshore wind energy is a key component of the renewable energies used by governments to reduce carbon (C) emissions from electricity production (Wang and Sun, 2012). Wind farms are often located in upland areas because most uplands are of low agricultural value, are distant from residential areas, and are windy (Cowell, 2010). Many UK uplands are peatlands, areas of land with an accumulated layer of peat, formed under waterlogged conditions from C rich plant material. These peatlands provide a special environment that hosts many rare fauna and flora (Bain et al., 2011) and represent a large stock of soil C, holding 48% of the total UK soil C stocks (Bradley et al., 2005). Because the high C content of a peat is partly due to waterlogged conditions, on drainage of the peatland, the peat can rapidly decompose, releasing large amounts of C as CO_2. This makes peat an important component of the UK C balance. Construction of wind farms can result in large losses of C due to removal of peat for foundations and due to drainage of peats around foundations, roads and other infrastructure, so it is important to ascertain whether C emissions will be reduced when wind farms are located on these C rich peatland soils.

With publication of the IUCN Peatlands Inquiry (Bain et al., 2011), peatlands have moved up the political agenda. For example, the Scottish Parliament's Rural Affairs, Climate Change and Environment Committee took evidence on the importance of peatlands for climate change mitigation in April 2012 (Scottish Parliament, 2012). Furthermore, following the decision at the 17th Conference of Parties of the United Nations Framework Convention on Climate Change (UNFCCC) in Durban, December 2011, to include wetland drainage and re-wetting as an electable activity under Kyoto Article 3.4 (UNFCCC, 2011), net removals of C from the atmosphere by peatlands can now be included in the National Inventories of Annex I (industrialised) countries, to help meet Kyoto Protocol

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* Corresponding author. Tel.: +44 1224 272702; fax: +44 1224 272703.
E-mail address: jo.smith@abdn.ac.uk (J. Smith).

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targets. The C balance of peatlands has, therefore, never been more important in policy terms, so any energy development on peatland requires scrutiny in terms of how it impacts upon the C and greenhouse gas balance.

When wind farm sites are drained for construction, there is a higher risk of net C loss if they are sited on peatlands than on mineral soils. A method to account for all C emissions attributable to a wind farm located on a peat soil has been developed by Nayak et al. (2010), widely adopted by the wind industry, and is currently being used by the Scottish Government in planning large-scale developments on peatlands (Scottish Environment Protection Agency (SEPA), 2012). Calculations using this approach suggested that wind farms on peats could reduce net C emissions if sites were strictly managed for maximum retention of C (Nayak et al., 2010). However, these calculations assumed that the present day fossil fuel mix would otherwise have been used to generate the electricity replaced. Here we examine the impacts on net C emissions of projected changes in the proportion of fossil fuels used to generate electricity.

2. Materials and methods

2.1. Calculation of carbon payback time

The purpose of using wind as a source of energy is to continue to provide the energy needed by society while reducing net C emissions from burning of fossil fuels (Aboumahboub et al., 2012). In order for a wind farm to provide a net reduction in C emissions, the losses of C due to the wind farm development must be less than the C savings achieved by avoiding fossil fuel use. This is often expressed as the C payback time, $t_{Cpayback}$ (years); the ratio of the total C losses, L_{tot} (t CO_2 eq.), to the annual C savings, $S_{turbine}$ (t CO_2 yr^{-1}) (Gibbs et al., 2008),

$$t_{Cpayback} = \frac{L_{tot}}{S_{turbine}} \tag{1}$$

If the C payback time is more than the lifetime of the wind farm, then no net reduction in C emissions is achieved.

2.2. Calculation of total carbon losses

In order to account for the C losses from the full life cycle of direct and indirect supply chain C inputs into the wind farm, a hybrid life cycle analysis (LCA) methodology can be used (Wiedmann et al., 2011; Acquaye et al., 2012). In this paper, we estimate the net loss of C due to wind farm development on peatland using the process LCA approach of Nayak et al. (2010) to calculate the net loss of C, L_{tot}, as the sum of

- loss of C due to production, transportation, erection, operation and dismantling of the wind farm;
- loss of C due to backup power generation;
- loss of C-fixing potential of peatland;
- change of C stored in peatland (due to peat removal and changes in drainage);
- C saving due to improvement of habitat; and
- loss of C-fixing potential and C stored in trees as a result of forestry clearance.

In this approach, loss of C due to production, transportation, erection, operation and dismantling of the wind farm is either supplied as an input value or estimated as a function of the turbine capacity. Losses of C emission savings due to backup power generation are calculated from the reserve capacity required for backup, the emission factor of the backup fuel and the reduced thermal efficiency of the reserve generation facilities due to the plant running at sub-optimal rate (Dale et al., 2004). The loss of C-fixing potential of the peatland is calculated from the area affected directly by infrastructure as well as the area indirectly affected by drainage (Stewart and Lance (1991)). The C fixing capacity of each unit area of affected peatland is either supplied as an input or estimated from observed rates of C accumulation (e.g. Turunen et al., 2001) and the time required until successful habitat restoration. The change in C stored in the peatland due to peat removal is given by the volume of peat removed and the C content of the peat. The loss of stored C due to drainage is calculated from the rates of CO_2 and methane emissions at different water table depths and air temperatures, and the time to restoration of the hydrology at the site. Additional losses of stored C as dissolved and particulate organic C are estimated as a proportion of the total CO_2 emissions from the peat (Worrall et al., 2004). The C saving due to improvement of habitat can then be accounted for as a change in the time to restoration of the hydrology and a change in the C accumulation rate. The loss of C-fixing potential and C stored in trees as a result of forestry clearance can also be included using estimates of the rate of C sequestration in the different tree species (Cannell, 1999). One process that has not been included in this approach is peat erosion due to catastrophic events, such as peatslides. Strong guidelines exist for minimising peatslide risk (e.g. Scottish Executive 2006), and it is assumed here that these guidelines are followed so that such events do not occur.

2.3. Calculation of annual carbon savings

The annual C saving achieved by avoiding fossil fuel use, $S_{turbine}$ (t CO_2 yr^{-1} $turbine^{-1}$), is given by the annual energy output from the turbine, $\varepsilon_{turbine}$ (MW h yr^{-1} $turbine^{-1}$), and the emissions that would have been incurred if that energy had been obtained from the mix of fuels replaced by the wind farm (the emission factor), EF (t CO_2 MW h^{-1}, Nayak et al., 2010),

$$S_{turbine} = \varepsilon_{turbine} \times EF \tag{2}$$

This means that the C payback time is inversely proportional to the average emission factor observed over the lifetime of the wind farm, EF_{ave} (t CO_2 MW h^{-1}),

$$t_{Cpayback} = \frac{L_{tot}}{\varepsilon_{turbine} \times EF_{ave}} \tag{3}$$

2.4. Input values for baseline calculations

Baseline calculations of the C payback time and net C emissions for wind farms on peatlands were done for a typical UK wind farm. This was defined as realising 30% of the turbine capacity (capacity factor), with an average annual air temperature of 9 °C, C content of dry peat 80%, water table depth of 0.2 m, regeneration time of bog plants 25 years, and C accumulation rate of bog plants 0.25 t C ha^{-1} yr^{-1}. Turbines were assumed to have a power of 2 MW and foundations of 18 m × 18 m × 0.9 m deep with associated hard-standing of 40 m × 22 m × 0.1 m depth, and a lifetime of 25 years. The effects of changes in site conditions and management were tested by adjusting input variables across the potential range of conditions; extent of drainage was adjusted between 0 m and 150 m, foundation dimensions between (10 m × 10 m) and (50 m × 50 m), length of non-floating access track from (0 km $turbine^{-1}$ to 1 km $turbine^{-1}$), and depth of peat drained between 1 m and 5 m.

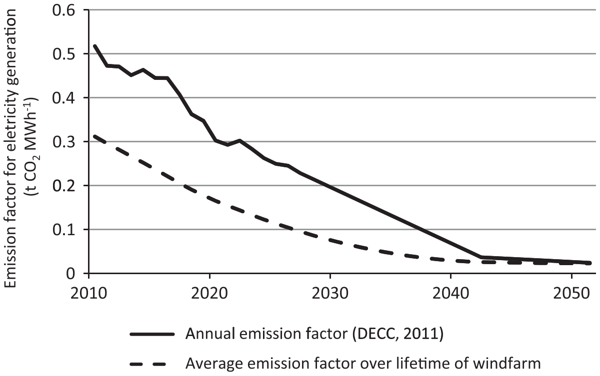

Fig. 1. Changes in emissions from the mix of fuels used to produce electricity in the UK. Average emission factor over the lifetime of a wind farm calculated assuming the lifetime of a wind farm is 25 years.

2.5. Emission factors

All calculations presented in this paper used the grid mix emission factors for the UK (Department of Energy and Climate Change (DECC), 2011) averaged over the assumed 25 year lifetime of the windfarm as shown in Fig. 1.

When calculating the potential of a wind farm to decarbonise electricity generation, the C emissions from the wind farm are usually compared to the emissions from the fossil fuels it replaces, so only the contribution of fossil fuels to the grid mix are accounted for in the emission factor chosen (e.g. Scottish Environment Protection Agency (SEPA), 2012). By contrast, in calculating whether a wind farm will provide an emission saving over other potential sources of electricity generation (fossil fuels, wind farms on mineral soils, tidal, nuclear etc), we need to compare the emissions from the wind farm to all the other types of electricity generation it will replace. Therefore, in these calculations, it is the total grid mix that is used, including both fossil fuel and renewable sources. This then directly compares the emissions that would occur if a wind farm was constructed on a peatland to the emissions that would occur if electricity was generated by any other means.

The average emission factor over the lifetime of the windfarm is used because emission factors from the mix of fuels used to generate electricity are projected to decrease in the future, due to use of Combined Cycle Gas Turbines up to 2025, and a higher proportion of renewable energies after 2025 (Department of Energy and Climate Change (DECC), 2011). This results in a change in the average emission factors as shown, for example, for the UK in Fig. 1, and a consequent change in the C payback time of wind farms constructed in the future. Similar decreases are expected in other countries, due to a move to a higher proportion of low-C power technologies; renewable and nuclear power are expected to account for more than half of all new power generation capacity added worldwide between 2010 and 2035 (International Energy Agency (IEA), 2011).

2.6. Effect of emission factor on net carbon saving at different sites

The threshold emission factor at which a site provides no net C saving, indicated by the C payback time exceeding the lifetime of the wind farm, is highly dependent on the conditions at the site, mainly the depth of the peat drained and the extent of drainage (Nayak et al., 2010). Therefore, these two variables were used to describe the range of sites that might be encountered. The depth of peat drained was assumed to range between 1 m and 5 m. There is considerable debate over typical extents of drainage observed in peats, with some authors suggesting that the drainage impact of ditches can extend as far as 400 m downslope (Lindsay, 2010), while an extensive global review of recommended drain spacings (McAfee, 1984) observed that drains are seldom spaced more than 40 m apart, suggesting the extent of drainage impact should also be considered within the same distance. This disagreement may be due to the formation of natural pipes within drained peats, which can significantly increase the extent of drainage over the lifetime of the wind farm (Holden, 2006), but would not be observed in a newly drained peatland and so would not be reflected in the positioning of drainage ditches. To capture the full breadth of scientific opinion, the extent of drainage was allowed to range from 0 m to 400 m.

The C payback time, $t_{Cpayback}$ (years), at a site was described with respect to the average emission factor during the lifetime of the wind farm by fitting an equation to the results obtained across the range of expected conditions,

$$t_{Cpayback} = a\ x\ EF_{ave}{}^{-b} \tag{4}$$

where a and b are constants that have been selected to provide the best fit between the equation and the results; for the UK, values published by Department of Energy and Climate Change (DECC) (2011) give a range of $EF_{ave} = 0.025$ to $0.45\ t\ CO_2\ MW\ h^{-1}$ (Fig. 1).

By substituting $t_{Cpayback} = 25$ years (typical lifetime of a wind farm) into Eq. (4) and rearranging, an equation was derived for the emission factor where the C payback time exceeds 25 years, EF_{25yrs} ($t\ CO_2\ MW\ h^{-1}$), and so the wind farm provides no net C saving

$$EF_{25yrs} = \left(\frac{25}{a}\right)^{1/-b} \tag{5}$$

By running the model at sites with different extents of drainage (0–400 m) and depths of peat drained (1–5 m), the values of a and b were derived for the different sites, and Eq. (5) was used to calculate EF_{25yrs} for each. From these results, a more general equation to determine EF_{25yrs} from the extent of drainage, D (m), was derived,

$$EF_{25yrs} = eD^2 + fD + g \tag{6}$$

where e, f and g are constants that are dependent on the depth of drained peat, again fitted to provide the best fit between the equation and the results. Using the standard quadratic formula (Sterling, 2010) to factorise Eq. (6) gives the extent of drainage above which there will be no net C saving, D_0 (m), for any given average emission factor, EF_{ave} ($t\ CO_2\ MW\ h^{-1}$)

$$D_0 = \frac{-f \pm \sqrt{(f^2 - 4e(g - EF_{ave}))}}{2e} \tag{7}$$

Because the negative term results in a negative value for D_0, which has no physical meaning, this is resolved to

$$D_0 = \frac{-f + \sqrt{(f^2 - 4e\ (g - EF_{ave}))}}{2e} \tag{8}$$

Finally, Eq. (6) was translated into the year after which the wind farm will provide no net C saving, Y_0, by fitting a polynomial equation to the average emission factors.

Calculations were completed for sites that were managed for maximum C retention (hydrology restored on completion of construction, floating roads used and no additional infrastructure installed), and for similar sites where hydrology was not restored, floating roads were assumed to sink, or additional infrastructure (such as cable trenches, borrow pits and equipment enclosures) was constructed. The impact on net C savings of each of these assumptions was investigated in turn.

3. Results

3.1. Changes in carbon payback time with emission factor

Changes in C payback time, for an example wind farm, due to projected changes in the average emission factor over the lifetime of the wind farm are shown in Fig. 2. The change in average emission factor is represented in Fig. 2 as the year of wind farm construction. As the extent of drainage increases, year of construction when the C payback time exceeds the assumed 25 year lifetime of the windfarm (and so no net C benefit of constructing the windfarm is realised) decreases. In this example, for an extent of drainage of 50 m, the C payback time exceeds the lifetime of the windfarm by year of construction 2040; for a 150 m extent of drainage, this will occur by 2030.

3.2. Effect of the emission factor on net carbon saving at sites managed for maximum carbon retention

Fig. 3 shows the equation derived for C payback time assuming an extent of drainage of 25 m and depth of peat drained as indicated in the baseline measurements (Section 2.4). Similar relationships were derived across the range of extents of drainage and peat depths simulated, and used to derive equations for the value of the emission factor when no net C saving is achieved, EF_{25yrs}.

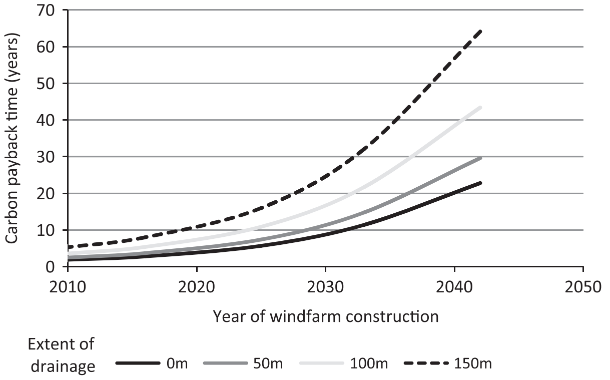

Fig. 2. Changes in carbon payback time for an example wind farm due to projected changes in average emission factor over the lifetime of the wind farm. Carbon payback time calculated by the method of Nayak et al. (2010) for an example wind farm with 2 MW turbines with foundations of 18 m × 18 m × 0.9 m deep, associated hard-standing of 40 m × 22 m × 0.1 m depth, managed for maximum carbon retention (using floating roads and no additional infrastructure) and a lifetime of 25 years.

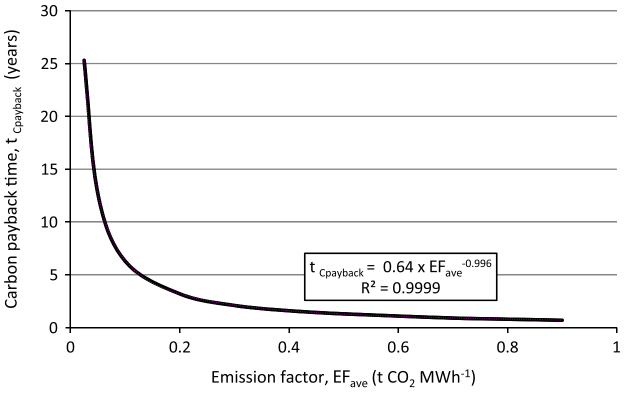

Fig. 3. Carbon payback time calculated for a range of emission factors for a typical UK site as given in the methods summary, assuming extent of drainage 25 m, no drainage of access tracks and restoration of the hydrology immediately following completion of foundations.

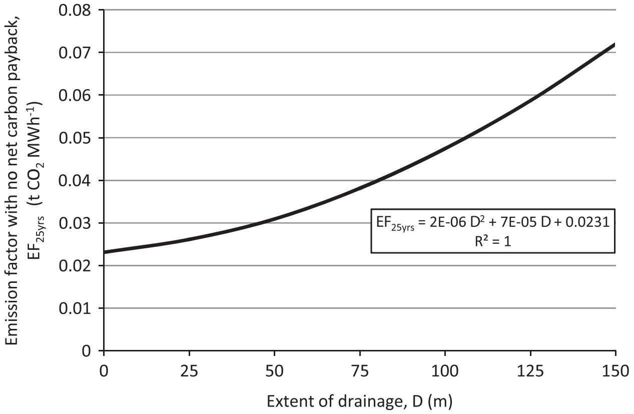

Fig. 4. Emission factor where no net C payback is achieved for a typical UK site as given in the methods summary across a range of extents of drainage, assuming depth of drained peat of 1 m, no drainage of access tracks and restoration of the hydrology immediately following completion of foundations.

Fig. 4 shows the equation derived for the emission factor where no net C saving will be achieved (EF_{25yrs}) with respect to the extent of drainage, D (m), for the example of peat drained to 1 m. The values of e, f and g obtained for different depths of drainage are shown in Table 1.

As illustrated in Fig. 5, the year associated with the average emission factor derived from the UK grid-mix emission factors provided by Department of Energy and Climate Change (DECC) (2011) is given by

$$Y_0 = 1994.79 \times EF_{25yrs}^{-0.0065} \qquad R^2 = 0.979 \tag{9}$$

This equation was then used to translate the emission factors with no net C savings into the year of construction of the wind farm (Fig. 6). The results show that in 2010, if sites are managed for maximum C retention by using effective floating roads, minimising infrastructure such as equipment compounds and cable trenches, and restoring the hydrology of peat around the foundations immediately after construction, most sites have the potential to provide net C savings even if a higher extent of drainage is assumed (Fig. 6). However, by the end of the lifetime of sites approved in 2010 (~2040), even sites with less than 25 m extent of drainage will provide no net C savings. This is due to the projected change in the emission factors.

3.3. Effect of emission factor on net carbon saving if hydrology is not restored

Similar calculations to those described in Section 3.2, but assuming sites were not restored, provide alternative values for the constants defining the emission factors where no net C savings are achieved at different extents of drainage and depths of peat drained (e, f and g, Eq. (6));

$$e = (-3 \times 10^{-7})d^2 + (1 \times 10^{-5})d - (4 \times 10^{-6}) \tag{10}$$

$$f = (-7 \times 10^{-6})d^2 + (5 \times 10^{-4})d - (8 \times 10^{-5}) \tag{11}$$

and

$$g = (1.8 \times 10^{-3})d - (2.13 \times 10^{-2}) \tag{12}$$

where d is the depth of drained peat (m).

The results of these calculations are given in Fig. 7. They show that even in 2010, significant C losses are expected at a high proportion of sites (Fig. 7). This suggests that the hydrology of the peat around foundations should never be left unrestored on

Table 1
Parameters describing the emission factor where C payback time exceeds 25 years for different depths of drained peat.

Depth of drained peat, d (m)	e^{a}	f^{a}	g^{a}	R^2
1	2×10^{-6}	7×10^{-5}	0.0231	1.0
2	2×10^{-6}	1×10^{-4}	0.0247	1.0
3	3×10^{-6}	1×10^{-4}	0.0268	1.0
4	3×10^{-6}	1×10^{-4}	0.0284	1.0
5	3×10^{-6}	1×10^{-4}	0.0301	1.0

[a] e, f and g are constants that are dependent on the depth of drained peat, fitted to provide the best fit between the equation and the results.

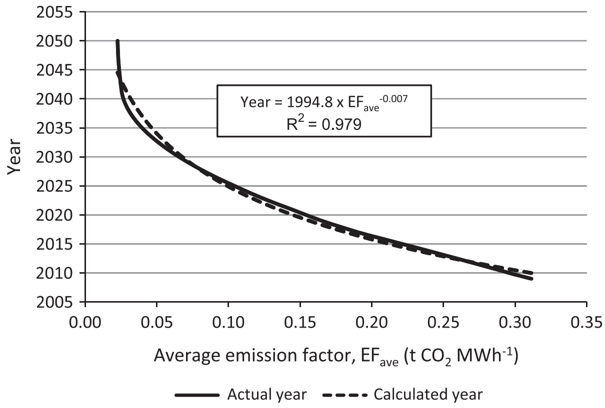

Fig. 5. Year corresponding to the average emission factor observed over the 25 year lifetime of a wind farm in the UK, EF_{ave}. The actual values (as shown in Fig. 1) are represented by the solid line. The values calculated by the equation fitted to the actual values are represented by the dotted line. The graph illustrates the goodness of fit between the two sets of values.

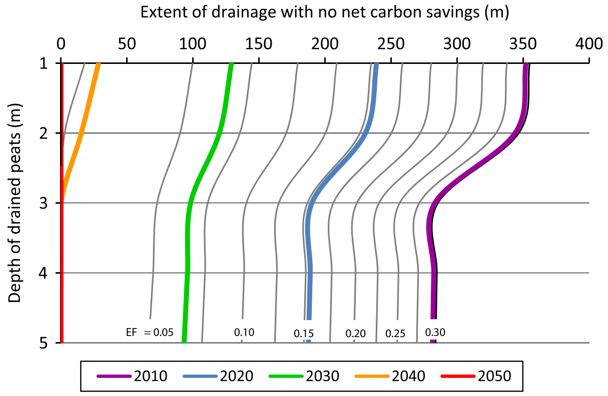

Fig. 6. Extent of drainage where no net carbon savings occur, at sites with different depths of drained peat and hydrology, that are fully restored on completion of construction. Carbon savings calculated by the method of Nayak et al. (2010) for example wind farm with lifetime of 25 years and 2 MW turbines with foundations of 18 m × 18 m, associated hard-standing of 40 m × 22 m × 0.1 m depth and managed for maximum carbon retention (floating roads and no additional infrastructure). Contours show results assuming different lifetime average emission factors. Coloured contours indicate results according to year of wind farm construction.

completion of construction of the wind farm as this will result in net C emissions from most sites.

3.4. Effect of additional infrastructure on net carbon saving

If floating roads sink or significant amounts of infrastructure, such as cable trenches, borrow pits and equipment enclosures are constructed, net C losses from wind farms constructed on peatlands could be very large. Additional infrastructure adds to the impact that the emission factor has on the C payback time. For example, if access tracks are constructed as either rock-filled or excavated roads, or if floating roads sink following construction and sustained use, the access track adds to the C payback time, and so the impact of the wind farm on C emissions increases, resulting in no net saving in C occurring at a higher emission factor (an earlier year of construction) than was observed without the access track. By repeating the above calculations but including the additional infrastructure on the site, an equation was derived for the change in the emission factor where the wind farm provides no net C saving due to the extra infrastructure, $\Delta EF_{25\text{yrs}}$ ((t CO$_2$ MW h^{-1}) (unit of infrastructure)$^{-1}$). As shown in Fig. 8, for drained access tracks, the equation for $\Delta EF_{25\text{yrs}}$ ((t CO$_2$ MW h^{-1}) (100 m access track)$^{-1}$) is linear

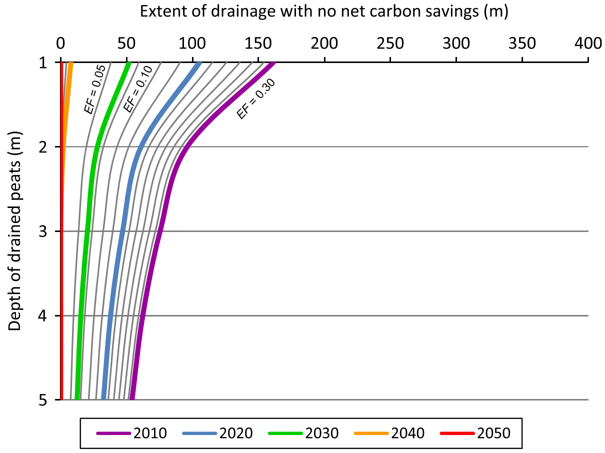

Fig. 7. Extent of drainage where no net carbon savings occur at sites with different depths of drained peat if hydrology is not restored on completion of construction. Carbon savings calculated by the method of Nayak et al. (2010) for an example wind farm with a lifetime of 25 years and 2 MW turbines with foundations of 18 m × 18 m, associated hard-standing of 40 m × 22 m × 0.1 m depth and managed for maximum carbon retention (using floating roads and no additional infrastructure).

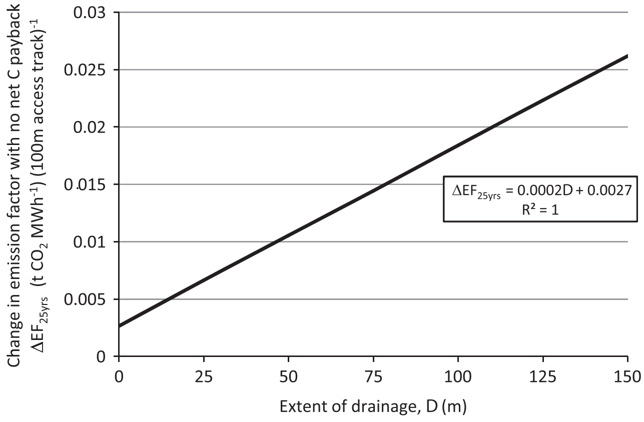

Fig. 8. Change in emission factor with no net C payback due to drainage of access tracks for a typical UK site as given in the methods summary across a range of extents of drainage, assuming depth of drained peat of 1 m and restoration of the hydrology immediately following completion of foundations.

$$\Delta EF_{25\text{yrs}} = (h \times D) + i \quad (R^2 = 0.9995) \tag{13}$$

and has slope, h, of 0.0002 (t CO$_2$ MW h^{-1}) (100 m access track)$^{-1}$ (m extent of drainage)$^{-1}$, and an intercept, i. The value of i varies with the depth of the access track, d (m), and is given by $i = 0.0027d - 0.0001$ (t CO$_2$ MW h^{-1}) (100 m access track)$^{-1}$. For the example of drained roads, Eq. (13) gives the change in the emission factor where no net C saving is achieved with every 100 m of road drained. Using Eq. (9), this translates to sites showing no potential for net C saving ~2 years earlier for every 100 m of track drained.

3.5. Effect of turbine power on net carbon saving

The C payback time for a wind farm is calculated from the ratio of the net loss of C due to the wind farm development with the yearly C savings achieved by avoiding fossil fuel use (Eq. (1)). The yearly C savings can be calculated from the typical percentage of the turbine capacity realised at the site (the capacity factor), p_{cap} (%), the power of the turbine, P (MW), the number of turbines, n_{turbine}, and the average emission factor, EF_{ave} (t CO_2 MW h^{-1}) (Nayak et al., 2010),

$$S_{fuel} = 24 \times 365 \times \frac{p_{cap}}{100} \times n_{turbine} \times P \times EF_{ave} \tag{14}$$

A site that provides no net C saving will have a C payback time equivalent to the wind farm life ($t_{Cpayback} = 25$ years). Substituting this into Eq. (1, 14) and rearranging gives an expression for the emission factor where no net C saving is achieved, $EF_{25\text{yrs}}$ (t CO_2 kW h^{-1})

$$EF_{25\text{yrs}} = \frac{L_{tot}}{25 \times 24 \times 365 \times (p_{cap}/100) \times n_{turbine} \times P} \tag{15}$$

Turbines are likely to be of higher power in the future and have associated larger foundations (Hansen et al., 2004). As shown in Eq. (15), the emission factor where no net C saving is achieved, $EF_{25\text{yrs}}$ (t CO_2 kW h^{-1}), is inversely proportional to the turbine power, P (MW). So if a turbine with power P_1 achieves no net C saving at emission factor $EF_{25\text{yrs}}$, then if the size of the foundations remain unchanged, a turbine of power P_2 will achieve no net C saving at emission factor $EF_{25\text{yrs}} \times (P_1/P_2)$. Therefore, to maintain the current level of C savings, the power of the turbine relative to the size of the base must increase in proportion to the decrease in the average emission factor over time. For example, for a turbine to provide a net C saving at sites with extent of drainage up to 100 m and peat drained to a depth of 5 m in 2040, the ratio of $EF_{25\text{yrs}}/P$ in 2040 would need to be equivalent to the ratio in 2030 (Fig. 6). This means that the turbine power would need to increase by a factor of 2.45 for the same size of foundations.

4. Discussion

The above calculations illustrate that changes in emission factors expected by 2050 are likely to reduce the C savings achieved when wind farms are located on undegraded peatlands. Even without accounting for the impact of additional infrastructure, if sites are restored, drainage for turbine foundations will result in no net C savings at most sites by ~2040, and if they are not restored, net C losses are already likely in 2010 at many of the sites constructed. Construction of infrastructure adds to the C losses; drainage of roads results in no net C savings ~2 years earlier for every 100 m of track drained. These effects may be partially offset by increases in turbine power with respect to the size of foundations. This may be facilitated by development of technologies such as piling (Tomlinson and Woodward, 2008), which reduce the need to excavate peats, even with larger turbines. If wind farms are not decommissioned at the end of their lifetime, but are instead used to site new turbines, there may be further potential for net C savings at the recommissioned sites by reducing the need to excavate new foundations through positioning the new turbine on top of the foundations of the previous turbine. In the future, because of changes in the emission factors, if wind farms located on peatlands are to provide a net C saving, it is essential that such construction options are used to maximise the ratio of the turbine power to the volume of foundations.

There is also potential to reduce the C payback time by using the financial resources available to wind farm companies to restore previously degraded peatlands and offset the losses from the wind farm itself. These practices might include restoration of previously degraded areas of the site, such as borrow pits, mined areas, existing roadways or heavily eroded gullies. Assuming that the hydrological status of the peat can be restored to a steady state that will allow the habitat to regenerate, the volume of peat restored should at least be greater than the volume of peat excavated for the construction, with additional restoration needed to account for any peat drained. The volume that should be restored will increase with delays in completion of restoration; if the restoration was complete only half-way through the wind farm life, then the volume of peat that should be restored would be doubled.

Further suggestions have been made that forestry planting could be used to offset the C lost from the wind farm. However, forestry planting can only be used to offset C losses due to felling of trees; losses due to decomposition of peats cannot be compensated for by planting trees as the longevity of the pool of C held in the trees is much less than that of the C held in the peats.

5. Conclusions and policy implications

Wind farms constructed on undegraded peatlands introduce higher risks of net loss of C than wind farms constructed on mineral soils, and must be strictly managed for maximum C retention if a net C saving is to be realised. Previous work (Nayak et al., 2010) has indicated that a benefit to terrestrial C stocks can be achieved by responsible management of sites and targeted use of resources to improve previously degraded sites. However, when projected changes in emission factors are accounted for, the potential for C saving is very much reduced and most peatland sites will show no net C saving. Even if constructing wind farms on undegraded peatlands is of value in reducing C emissions today, it is not likely to be so in the future. This suggests that the construction of wind farms on undegraded peatlands should be avoided. If this results in a reduction in renewable energies, the predicted reduction in emission factors might not be realised. However, given that wind farms could be sited solely on non-peatland sites, and that other forms of renewable energy are available to meet emission reduction targets, the exclusion of wind farm development on peatland would not be expected to significantly impact future emission factors. Given the clear advantages in terms of C payback time of locating wind farms on mineral soils, and the marginal future C savings provided by locating wind farms on peats, construction of wind farms on undegraded peatlands is best avoided wherever practicable.

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