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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.

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

* 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.