ORAL HEARING ON THE PROPOSED DEVELOPMENT COMPRISING 25 NO. WIND TURBINES, 4 BORROW PITS, SUBSTATION, PEAT DISPOSAL UNITS, CLEARCUTTING OF CONIFER PLANTATION AT STRABOY, MEEALARGAN, LOUGHCRILLEN, MULLNAMIN BEG, DERK BEG AND DERRYLOUGHAN TOWNLANDS, GLENTIES, CO. DONEGAL BY STRABOY WIND ENERGY LIMITED

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BRIEF OF EVIDENCE OF: Dr Olivia Bragg

Introduction

My name is Olivia Bragg, and I am a Research Fellow attached to the Geography Department at the University of Dundee, Scotland. My expertise is in wetland ecology and hydrology (ecohydrology).

I have three academic degrees. I read a combination of physical and biological/ecological subjects within the Natural Sciences tripos at Cambridge University (B.A. 1975, M.A. 1979) before moving to Scotland to develop an interest in peatlands that began in the fens of East Anglia. My doctoral research was carried out at the Department of Biological Sciences at the University of Dundee, and focused on characterising the newly described acrotelm layer of peat bogs. I was then engaged as a Postdoctoral Research Fellow to undertake a project on *Hydrology and Drainage of Mire Systems* which continued for seven years. My attachment to the University of Dundee then became honorary and I continued to undertake ecohydrological work on peatlands for various organisations in the UK and overseas as a private consultant. In 1996 I returned to University employment as a Research Fellow in Geography, specifically to undertake a series of projects relating to implementation of the Water Framework Directive for rivers and lakes in Scotland which culminated in development of the Lake Habitat Survey methodology, but also to continue my work on peatlands.

I am a member of the British Ecological Society (BES), the International Mire Conservation Group (IMCG), the International Peat Society (IPS) and the British Hydrological Society (BHS). I am currently Editor of the IMCG/IPS academic journal *Mires and Peat* and a member of the Main Board of IMCG. I was formerly Secretary of the BES Mires Research Group.

My experience of peatland wind farms began in 2004 when I carried out a detailed appraisal of the Derrybrien development and bog slide in collaboration with the University of East London. I have since evaluated numerous wind farm proposals and sites on behalf of various organisations, mostly in Scotland, and was engaged as peatland advisor to the Viking Energy Partnership during preparation of EIS documents for their wind farm development on Shetland. I have twice provided specialist advice on windfarm peat slides that have occurred on Irish Forestry (Coillte) land, in conjunction with the Forestry Stewardship Council certification scheme. In 2008 I co-organised the IMCG symposium *Wind Farms on Peatland* in Santiago de Compostela, Spain, to share knowledge about the international extent of peatland wind farm issues and the range of scientific and practical knowledge available to support those working on peatland wind farm developments.

My role here is to identify and comment on points of concern with the parts of the Straboy Wind Farm EIS that are within my field of expertise. Broadly, this relates to potential interactions of the proposed development with functioning of the peatland-and-water system. I have focused mostly on EIS Section 5.2 (Soils, Geology and Hydrology) and related Appendices, but have also read the Ecology section in Appendix F. Additionally I have seen some of the related evidence already presented at this hearing, notably the two submissions from Dan Keohane. My comments focus on the peat stability assessment, the viability of the peat regeneration areas, and (briefly) the design of infrastructure.

2. Peat Stability Assessment

<u>Overview of the peat stability assessment presented for Straboy Windfarm</u>

The assessment of peat stability is presented in the EIS Sections 5.2.2.5 and 5.2.4.1. It appears to have involved the following steps:

1. Winter field survey (Oct–Dec 2009, Oct 2010 and Feb 2011) involving measurement of peat thickness by probing at 786 points and un-drained shear strength (shear vane tests) at 72 locations. These appear not to be evenly distributed across the site, but rather to be focused in the vicinity of proposed infrastructure and thus to follow the routes of planned windfarm tracks including ones that were planned but later abandoned (EIS Figure 5.2.4). Ground conditions between probes and other site features (including peat slippage north of T15) were noted during fieldwork.

2. The results of the field survey were used to inform development of the site layout. Un-drained shear strength of peat, after correction for friction, ranged from 6 kPa to 66 kPa. Values above 30 kPa were considered to be ‘high’. Humification values (von Post scale) were 5–7. Peat thickness ranged from zero to >5.1 m. Areas with peat thickness >1.5 m (described as ‘deeper peat’) were identified and eight ‘larger’ examples avoided when selecting locations for the various elements of windfarm infrastructure. Slopes are described as variable, ranging from near flat to around 40º. Steep slopes were also avoided in creating the layout ‘as far as possible’ but roads do cross areas with slopes up to 25º.

2. A review of the occurrence and causes of peat landslides. A primary information source identified is *Landslides in Ireland* (GSI – Irish Geological Survey), which is stated to identify areas susceptible to landslide on the basis of (a) peat cover and (b) slopes greater than 15º.

3. Description of a qualitative risk assessment procedure developed with reference to the ‘Scottish Executive guideline on *Peat Landslide Hazard and Risk Assessment …*’ (see Footnote 3). This derives a Hazard Ranking as the product of Hazard and Exposure, where Hazard is the ‘likelihood of the peat landslide event occurring’ and Exposure is ‘the impact and consequences that the event may have’. The estimation of hazard involves dividing the site into three zones (A: peat thickness >1.5 m, slope <5º; B: peat thickness >1.5 m, slope typically 5–10º; C: peat thickness <1.5 m, slope up to 40º). A global Factor of Safety (FoS) value is given for each zone (A: 2–5; B: 2; C: >5); and on this basis, a probability of landslide for each zone is ‘qualitatively’ assigned. The probabilities are: ‘1 in 10^7 to 1 in 10^2 - unlikely’ for Zone A, ‘1 in 10^2 to 1 in 10 - likely’ for Zone B; and ‘< 1 in 10^7 - negligible’ for Zone C. Exposure is estimated by calculating the fraction of the developer’s total investment in the windfarm project (around €75 million) that would be spent on ‘cleanup’ after a peat landslide (€750,000–1,000,000, i.e. a ‘low-impact’ 1–2%); and subjectively upgrading to ‘high-impact’ on the basis of environmental costs. It is then stated (twice) that the likelihood of a construction-related peat landslide will be reduced from ‘likely’ to ‘unlikely’ through ‘mitigation’ achieved by modifying road construction methods.

Neither the calculation of FoS values nor the basis upon which probability of peat landslide is derived from them is described in Section 5.2 of the EIS, but there is a reference on page 86 to Appendix 5.2-2, which promises further explanation of the hazard ranking procedure. In fact, this amounts to a un-credited copy of page 33 of the Scottish Executive guideline which begins and ends mid-sentence and is not even identified as a separate Appendix. It was initially interpreted as the result of a mistake in the planning authority’s copying process and much effort and time have been spent requesting, awaiting and searching through multiple copies of the Appendices for full details of the FoS calculations.

A related reference is the section in the “Supplementary Brief of Evidence of Dan Keohane” dated 18 October 2012, which describes the assessment of peat stability for one of the two ‘peat regeneration areas’ (PRAs). This gives the standard formula for calculation of FoS:

$$FoS = \frac{shear\_resistance}{shear\_force} = \frac{s_u}{yz \sin B \cos B} \quad [1]$$

where FoS is Factor of Safety; s_u is un-drained shear strength (from field measurements); y is the bulk unit weight of peat; z is peat thickness; and B is the angle of slope. A single FoS value (2.1) for the PRA (PRA-1) is calculated by inserting values of 3 kPa for s_u, 10.3 kNm^{-3} for y, 1m for z and 8º for B. The procedure outlined above is then more or less followed with no further explanation of how the likelihood of peat landslide is derived from FoS; 'cleanup' costs (only) are mentioned as the basis for determining exposure.

Comments arising

Factor of safety is the ratio of maximum strength of a material to the load to which it will be subjected in use, and is equal to unity when the material is just strong enough to perform the intended function. Often, engineers build in a Margin of Safety (MoS), which is equal to (FoS - 1). In the context of the stability of peat on a slope, Equation [1] calculates FoS as the ratio of shear strength of the peat to the sum of the forces (shear stress) tending to make it move downslope (i.e. to simply slide sidewards), and values exceeding 1.5 are considered satisfactory. However, when dealing with peat, some (leading) practitioners in Ireland halve their measured values of s_u (and thus the values of FoS delivered) in light of recent research indicating that field shear vane testing over-estimates the true strength of this material[1].

Factor of Safety has been criticised as a basis for slope stability assessments relating to peatland because it is based on models developed for mineral soils that each represent only a single failure mechanism[2], and reflect very poorly the variety of mechanisms that can trigger movement of peat (Table 1). In response to such criticism, the Scottish Government[3] developed best practice guidance for identifying, mitigating and managing peat slide hazards and their associated risks by a combination of slope stability analysis (FoS calculation) and hazard risk ranking.

> "A peat landslide hazard zonation plan and accompanying risk register should be prepared…. Zoning on the plan (or map) should reflect the number of instability indicators in each zone. For example, a 'zone' of steep slope (>10°) with moderately deep peat exhibiting collapsed pipes and tension cracking and with a modelled Factor of Safety close to 1.0 would be higher on the Hazard scale than a zone of flat (<1°) terrain with shallow peat, few or no instability indicators and a high Factor of Safety. The definition of zone boundaries, and the scales applied to each zone should be determined by the competent person(s) on the basis of the site evidence and expert judgement. Such judgement is often best applied by a panel of technically competent persons with sufficient and appropriate experience of characterising peat hazards."

Specialist consultants have developed interpretations of this guidance for use in wind farm EIS work that differ in detail from one another. Table 2 compares the instability indicators considered in a Peatslide Risk Assessment Methodology (involving engineering judgement) developed for an example Scottish wind farm development with those included in a "Spatial Peat Stability – Qualitative Risk Assessment" (SPS-QRA) procedure developed by geologists for use in Ireland. Both approaches recognise the importance of peat thickness, slope, characteristics of the land surface, some indicator(s) of wetness and evidence of incipient peat failure as being important, and six of the SPS-QRA (Irish) factors map more or less completely onto five of the Scottish ones. The Scottish approach regards the factors identified as neither equally important nor all amenable to analysis.

[1] In a peat stability analysis recently undertaken as part of the EIS work for another proposed wind farm in Ireland, a correction factor of x0.5 was applied to values of s_u obtained by field shear vane tests (SVT), on the basis of the following reference: Mesri, G. & Ajlouni, M. (2007) Engineering properties of fibrous peats. *Journal of Geotechnical and Geoenvironmental Engineering*, 7, 851–866.

[2] in this case translational sliding; formulae describing rotational failure are also available.

[3] Scottish Government (2006) *Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments*. Scottish Executive, Edinburgh, 72 pp.

The presence of tension cracks is regarded as a warning of imminent failure that would override any other assessment, but only three of the factors (terrain surface plus classified peat thickness and slope) are used in the systematic assessment. The SPS-QRA approach affords equal weight to each of the eight risk factors but identifies as Priority Risk Zones areas where any three of them overlap. Shear strength is measured at multiple locations including all turbine sites, and a separate FoS value calculated for each location. The resolution achieved is sufficient to support micro-siting of turbines to minimise peatslide risk; in one example, two turbines were moved such that FoS increased from 23.6 to 65.3 and 29.9 to 36.2, respectively.

Although the procedure described in the Straboy Windfarm EIS can be recognised as a different interpretation of the same guidelines, I have never before seen such a minimal approach presented in support of a windfarm planning application. Differences from practice established by other experts in Scotland and elsewhere in Ireland include:

- Only two risk factors (peat thickness and slope) are considered in defining the hazard zones; other methodologies recognise the importance of at least eight factors and use at least three in systematic assessments of peat stability.
- Slope categories are distinguished for one of the peat thickness classes but not the other; thus it is implied that the stability of peat less than 1.5 m thick is independent of slope, even though the best available quantitative analysis (FoS) expressed by Equation 1 indicates that it does vary with slope.
- Some known risk factors were not recorded during the field survey; others such as land use differences (e.g. grazing *versus* forestry), erosion and peat slide scars, and the presence of swallow holes, were noted but are not taken into account in assessing peat stability.
- Although shear strength data were collected for at least 72 locations including those proposed for turbines, only three or four generic FoS values were calculated; it is not clear whether these are minimum, maximum or average values for the zones defined.

As one example of a location that might have been identified as 'higher-risk' from the data that were collected, let us consider probing location P79, which lies on the track approximately 85 m south-west of Turbine 24. The field survey data describe a "flat area at north-east corner of failed forestry" and give peat thickness as 4.0 m. Peat strength was measured at different depths, yielding values of ranging down from 22 kPa to 5 kPa. On this basis, three overlapping risk factors (thick peat, low shear strength and previous disturbance by forestry operations) might be flagged.

Peat that slides will do most damage if it ends up, for example, in a residential area or on land that is designated for nature conservation; or in a watercourse whose pollution could prejudice water supplies, sensitive biota or fisheries. As more and more wind farms are built, it is becoming clear that construction work does cause unpredicted peat failures from time to time. Some are hardly considered noteworthy because they have occurred in places where there is no route by which the displaced peat can reach sensitive receptors, or because the peat has been successfully contained before it reached them. Thus, a desirable continuation of the risk assessment procedure is to consider potential pathways to receptors and assess the severity of any impacts on these receptors as a guide to mitigation needs[4]. The populations of freshwater pearl mussel in the Owenea River 3 km downstream of Straboy are notably sensitive receptors for any displaced peat that reaches the Strachashel River (see Paragraph 2.107 of the Ecological Report). As most of the wind farm site drains into this river, this is the most likely route downstream for any displaced peat that cannot be contained; and we know from Derrybrien[5] that peat can travel much farther than 3 km through a river system. Thus, it would seem prudent to take an especially precautionary approach to any risk of peatslide identified for the Straboy proposal.

[4] Uglow, I. (2010) Peat Stability – Risk and Hazard Assessment. Presentation. Online at: http://www.igi.ie/assets/files/peat_stability/08%20Risk%20Assessment%20Ian%20Uglow.pdf

[5] Lindsay, R.A. & Bragg, O.M. (2005) *Wind farms and blanket peat: a report on the Derrybrien bog slide*. Second edition, University of East London Press.

The conclusion of the Straboy peat stability analysis that, for Zone B, the '*project may proceed pending further investigation to refine assessment and mitigate hazard through relocation or re-design at these locations*' suggests an expectation that substantial changes to layout and design may be implemented after planning permission is granted. It would be unusual for planning permission to be granted with authorisation for changes that go beyond small-scale micro-siting adjustments, and more in line with practice elsewhere to carry out a rigorous high-resolution peatslide risk assessment as part of the initial EIS work. In this case the outcome of the broad-brush peat stability assessment that has been carried out does little to inspire confidence that there is low risk of peatslide at this site. Although the FoS values derived for the three zones (A: 2–5; B: 2; C: >5) all exceed the 'satisfactory threshold' of 1.5 as presented, they would fall below it (to unity) for Zone B and at least part of Zone A (1–2.5) if the 50% reduction of field-measured shear strength (s_u) values recommended by latest science (see Footnote 1) were applied.

3. Peat Regeneration Areas (PRAs)

<u>Overview of EIS treatment</u>

So-called 'waste peat' is a recurring problem when wind farms are constructed on peatland. Because it is soft and compressible, it must be removed down to competent bedrock where heavy infrastructure is to be installed or heavy machinery used (e.g. at turbine bases and crane hardstandings). Environmental regulations often stipulate that all waste peat generated is disposed of within the confines of the site boundary. Peat proper (which is found beneath the surface turves) can sensibly be used for lining cable trenches and in habitat restoration, e.g. to partly fill the sections of ditches between dams; but there is usually an embarrassingly large surplus. It has proved problematic in Scotland when used to fill borrow pits because it creates areas of 'bottomless quagmire' that are hazardous for people, machinery, livestock and wildlife; and if spread in a fairly thin (1–2 m) layer over the ground surface, which results in its drying out and being washed off into watercourses. A possible innovation recently encountered in Ireland was a plan to place surplus peat in a Peat Deposition Area (PDA). For the Straboy proposal, two Peat Regeneration Areas (PRAs) are proposed. Information about these has been found in Section 5.2.4 (page 91) of the EIS, in the Peat Management Plan included in Appendix F, and in the Supplementary Brief of Evidence of Dan Keohane. Across the various texts and maps I have seen, these features are termed interchangeably as PRAs and PDAs and in one place we read that "the acrotelmic peat will be harvested from the peat disposal areas before removal of acrotelm turves and before excess peat is dumped there if scheduling is feasible". Thus it appears that the PRAs are intended to be, primarily, waste peat dumps.

Two PRA areas are identified. Both are on the lower slopes at the southern side of the windfarm site. PRA-1, to the west, is an area of peatland that has been partly cutover, with a peat layer that varies in thickness from zero to 1.5 m. It lies on a stepping slope above several houses, with its southern edge approximately 150 m upslope of the nearest one. The topography is described as a series of flat areas connected by locally steep (10º) ramps, and a slope angle of 8º is selected for the calculation of FoS in the supplementary evidence. PRA-2 appears to be a fairly similar area close to the entrance of the proposed windfarm site. Here, peat thickness ranges from 0.3 to 1.6 m and slopes range from 2º to 15º. Each PRA is divided by a drain; PRA-1 has wet heath vegetation whereas PRA-2 is described as blanket bog. It is noteworthy that the Ecology section (page 20) of the EIS mentions the presence of a non-calcareous spring on the northern boundary of PRA-1. Various estimates have been given of the volumes of peat to be placed in PRAs and the areas that will be covered, but the intention is to spread waste peat over parts of both areas to a depth of around 1.0 m (intended depths of <1.5 m and <1.1 m are also mentioned). Before this is done, berms will be created to prevent downslope movement. In the Appendix, these are described as (boulder) clay berms seated on subsoil or bedrock which will be created from overburden subsoil sourced from the PRAs themselves and other locations across the site, specifically the four borrow pits. Thus, presumably, they will be laid in trenches dug through the peat layer. It is not clear how much of the *in-situ* peat elsewhere on the PRAs will be disturbed to acquire sufficient subsoil to create the berms, which will be 0.7 m high and are apparently planned to be water-retaining so that gaps to permit surface water escape will be required. A difficulty with this description is that the material stated to overlie bedrock on the middle and lower slopes is described elsewhere in the EIS and supplementary evidence as glacial till consisting of “firm, red-brown slightly clayey silty sand with gravel” at the existing rock borrow pit (near T23), and as “grey-brown gravely silt” at the substation location (near the site entrance). Gravel and sand are free-draining materials and would thus impart totally different water transmission properties to the berms than clay, which is impermeable. Further uncertainty in this respect is introduced by the supplementary evidence, which contradicts the EIS information by stating that the intended material for the berms is rock.

The intention is that, once the PRAs have been covered with peat, vegetation cover will be established “as soon as possible in order to avoid erosion of stored peat”. Unfortunately, there is no clear plan for achieving this. Available options that are mentioned include partially covering the PRA with turves of surface (acrotelm) peat, hydroseeding, spreading cuttings of bog vegetation, and methods developed for restoration of commercially cutover raised bogs in Canada that involve spreading homogenised bog moss (*Sphagnum*) and straw mulch on bare peat surfaces. Trialling of methods on the PRAs is proposed. No timescale is given for the trials, but these will presumably need to continue through at least one growing season and thus introduce a delay of at least one year before roll-out of the optimal methods could be undertaken. Thus, the soonest possible time when vegetation cover could be established may not be immediately after the PRAs are filled, introducing the prospect that the translocated peat will dry out and erode meantime.

<u>Comments arising</u>

The aspiration to establish bog vegetation on these areas is ambitious. A fundamental requirement will be to establish suitable hydrological conditions, such that the water table remains close to the upper surface of the translocated peat layer. The water transmission characteristics of the berms will be a major factor in determining whether or not this can be achieved, and it is possible to envisage scenarios with permeable berms in which the translocated peat will always be well-drained and unable to support bog vegetation. Experience from elsewhere is not encouraging. I know of two examples where waste peat – in one case placed in a borrow pit and in another spread in a 1–2 m thick layer across a felled forestry area - failed to re-vegetate and caused ongoing water purity and ground safety concerns; and of no examples where bog vegetation has been successfully established on waste peat from a windfarm. The revegetation methods mentioned in the EIS were mostly developed for raised bogs and may not be suitable for the blanket peatland at Straboy; for example the straw mulches that are necessary to create suitably moist conditions for the establishment of bog mosses on flat peat fields in eastern Canada may not survive a windy day on a hillside in western Ireland. No reference has been found in the Straboy EIS to the outcome of long-term trials of re-vegetation techniques for eroded blanket peat in the English Pennine Hills, where broadcasting of a mixture of meadow grass seed and fertilizer has proved to be the only viable method for establishing an initial cover of vegetation. This may be the only way in which any vegetation could be established on the Straboy PRAs in the short term.

Given that the PRAs are to be equipped with ‘berms’ whose intended function appears similar to that of check dams, calculation of FoS values may be less than appropriate. However, as this has been undertaken by the developer, a comment on the method is called for. The calculation described beneath Equation [1] considers only the translocated peat and ignores the peat layer that is already present, which is “typically 0.3–0.6 m deep, but ranging up to 1.5 m”, although it is not intended to cover existing (’deep’) peat layers that are more than 0.7 m thick. Therefore, a more credible treatment would calculate FoS for both the existing ~0.5 m peat layer, and for this layer with a 1 m surcharge of additional peat. Given the likelihood that *in-situ* peat will be disturbed in order to access the mineral material beneath for berm construction, the shear strength value for disturbed peat should be used in both calculations. Using these values, Equation 1 gives FoS values of 4.2 (stable) for the existing peat layer and 1.4 (potentially unstable) for this layer with surcharge. This result has also been obtained independently in a commentary provided by Dr Padraig Ó Catháin (page 9; FoS for a surcharged peat layer 0.5 m thick = 1.41). If the correction for over-estimation of shear strength by hand vane measurements is applied (Footnote 1), these values reduce to 2.1 (stable) for the existing peat layer and 0.7 (unstable) for this layer with surcharge. Thus, it seems that effective berms will be essential to prevent translational sliding of peat placed on PRA-1.

It is perhaps more worrying that the manipulations to be performed on the PRA may increase the tendency for peat to become unstable through well documented mechanisms other than the simple translational slide modelled by the FoS calculation. The insertion of berms to ground bearing level will create a route for water to penetrate rapidly into the till layer beneath the peat. This could, especially during heavy rainfall following a period of dry weather, create conditions for a peat slope failure triggered by a build-up of hydrostatic pressure in the substratum causing liquefaction of the basal peat or mineral layer (see Table 1), which would not necessarily be contained by the berms. The presence of the spring at the upslope edge of the PRA is of particular concern in this context. Obviously, this is a 'worst-case' scenario based on incomplete knowledge of the site. However, in view of the proximity of housing downslope, it is a possibility that should be fully explored through detailed field investigations before implementation of the plans for PRA-1.

4. Design of roads and turbine bases

It is far from true that any peatslide risk introduced by windfarm construction can be 'mitigated' by modifying the design of infrastructure (Section 2 above). However, the principle that best practice should minimally disturb the natural pattern of water movement through peat is sound. The best possible long-term outcome for a peatland windfarm can be expected if the infrastructure is made 'hydrologically invisible', i.e. it will allow the seepage water that maintains the peat blanket to pass without obstruction or diversion. No designs that completely fulfil this criterion are (yet) available, but the authors of the Straboy EIS are clearly aware of the aspiration and introduce some interesting new points of design and practice. The time required to unravel the unusual treatment of peat stability assessment has precluded a full discussion. However, there are inconsistencies that cannot pass without note, and the main ones are listed below.

- Due to the rough terrain and steep cross-falls encountered at Straboy, most of the windfarm roads will be laid on bedrock or till if present, after removal of any peat. However, sections of so-called 'floating' road are proposed where deep peat is to be crossed. The designs presented for both types incorporate provision to allow water to move from one side of the road to the other, but may not prevent it from being diverted along the line of the road in all situations. However, the embankments are to be covered with peat and re-vegetated and it is not entirely clear that this will be compatible with maintenance of the provision for water to pass unhindered through them.

- At one point, a description of loading peat to build up subgrade strength beneath 'floating' roads is presented. It is laudable that monitoring of the dispersal of pressure during this (sinking) process is proposed; it is normally omitted from wind farm construction practice on the basis of excessive cost relative to benefit. However, Paragraph 2.207 of the Ecology chapter states that "On deep peat, floating roads will be constructed on geotextiles over pilings to maintain hydrological connectivity", which implies that these roads will be prevented from compressing the subgrade. There are important differences in the way that the two designs will interact with the ecohydrology of the peat blanket, and clarification of intentions is required.

- It appears that the fill around turbine bases will be permanently drained, which will promote point drainage of the surrounding peat blanket. An alternative that appears not to have been considered is to increase the mass of steel reinforcement in the concrete turbine foundation sufficiently to counteract buoyancy so that drainage can be omitted. At some windfarms, turbines are supported on piles so that no base excavation is necessary (although crane hardstandings are still required). Each design has pros and cons but the latter two may have advantages for the integrity of peatland.

Table 1. Summary of peat failure mechanisms leading to mass movements identified by Warburton *et al*. (2004)[6].

Failure mechanism	Description	Hydrological control
Shear failure by loading	Hydrological loading – weight of absorbed water (rainfall, snowmelt) or snow.	Absorption of water into the peat mass.
	Increase in shear stress – hydrostatic pressure generated by water-filled cracks, ponds, lochs.	Development of standing bodies of water in the peat.
	Catastrophic loading – rapid increase in peat mass exceedance of shear strength.	"Hydraulic mining" by heavy localised cloudbursts.
Buoyancy effect	Generation of artesian pressures.	Routing of water to base of peat (pipes, drains).
	Increase in interstitial pore-water pressure and reduction in cohesion.	Transfer of surface water to base of peat through peat matrix.
Liquefaction	Basal peat slurried by increased water content (exceedance of liquid limit).	Routing of water to base via watercourses, infiltration, surface routing.
	Basal clay slurried by organic acid dispersal (passing of liquid limit).	Long-term peat/clay interface chemical interaction.
	General increase in basal moisture content by routing of artificial drainage.	Downslope drainage impedance by blocked drains; enhanced upslope drainage by open drains and cuts.
Surface rupture	Swelling of basal peat leading to rupture of the drier surface.	Increase in water availability to basal peat.
	Relative swelling of basal peat by contraction of surface during drought.	Reduction in surface water content.
	Long-term depth creep inducing surface rupture or shear failure.	Development of seepage pressures.
Margin rupture	Removal of underlying support by stream action – release of basal peat.	External hydrological processes.
	Removal of underlying support by peat cutting.	Anthropogenic cause.

Table 2. Comparison of criteria types considered in the QMEC Spatial Peat Stability Qualitative Risk Assessment (SPS-QRA) with those considered in an example similar procedure developed by a different consultant for a proposed wind farm site in Scotland.

Factors considered in a Scottish example	*QMEC risk factors*
(a) Peat depth (4 categories: <0.5 m to >2.5 m; deep is >1.25 m)	(1) Peat depth >2.0 m
(b) Slope angle (5 categories, 3-degree interval)	(2) Slope >5 degrees
(c) Terrain surface	(5) Historic and current land use factors (7) Geology (soft / rockhead etc.)
(d) Moisture content and water table level	(8) Hydrology and hydrogeology
(e) Presence of tension cracks	(6) Geomorphological factors, erosion and stress indicators, landuse factors
	(4) Peat humification >H6
	(3) Shear strength
(f) Interface between peat and underlying material	
(g) Orientation of track construction to slope	
(h) Existing or new infrastructure	

[6] Warburton, J., Holden, J. & Mills, A.J. (2004) Hydrological controls of surficial mass movements in peat. *Earth Science Reviews*, 67(1–2), 139–156.