WIND FARM ACCESS ROADS
- TWO DECADES OF FLOATING ROADS

Construction of wind farms in the UK and Ireland, sited on peat moors, goes back to the late 1980's. Wind farms have promoted the practice of stabilisation, allowing experience to be gained, techniques to be developed and products to be created to permit practicable and economic construction. Latterly these have been described as 'floating roads' when constructed on peat.

Good practice guidance has recently been provided by government bodies and this paper describes the practice derived from the authors' involvement in their design. As floating roads are accepted as an appropriate technique, the emphasis is now placed on considerations other than the mere possibility of building such roads and more on the embodied energy in the construction procedures and the associated carbon dioxide emissions. The benefits of using monolithic geogrids in ground stabilisation works are evaluated in terms of cost savings derived from the reduction in the required aggregate thickness and the associated construction effort. Cost can be measured in two ways: cash and carbon. The authors have developed a carbon calculator which estimates carbon dioxide emissions. This paper presents the estimated magnitude of greenhouse gas emissions for UK and Ireland wind farm projects that are located in areas of peat.

1. INTRODUCTION

Monolithic punched and drawn polymeric geogrids have been used since the early 1980's to stabilise aggregate in access roads constructed over compressible peat. Such 'monolithic' geogrids were used to provide safe access over soft ground in public roads in the Shetland Islands and infrastructure works on the Falkland Islands. The first recorded UK wind farm access road to use geogrids was Ovenden Moor near Halifax, UK in the mid-1980's.

Since that time, numerous wind farm projects have been constructed in and many are constructed over peat. Most of the resulting 'floating roads' have incorporated geogrids. The authors' record comprises 35 projects and 25 of them had sufficient information recorded to make possible some analysis.

Upland areas of northern Britain, where the majority of on-shore wind development is found, contain large areas of bogland. Generally, these areas are characterised by low land values and where the land is not put to gainful use other than forestry development. The ground is invariably poorly-drained with the water table at, or near, the surface. Un-stripped blanket peat in these upland areas, (i.e. peat with the vegetative surface cover left intact), usually can be regarded as a soil, for design purposes, equating to an undrained shear strength from $12kN/m^2$ to $24kN/m^2$.

A typical contemporary wind farm (Figure 1) consists of primary access routes such as spine roads from the site entrance. These join secondary routes containing arrays of turbines. In turn, these lead to spurs, which are relatively short lengths of roads containing perhaps only one or two turbines.

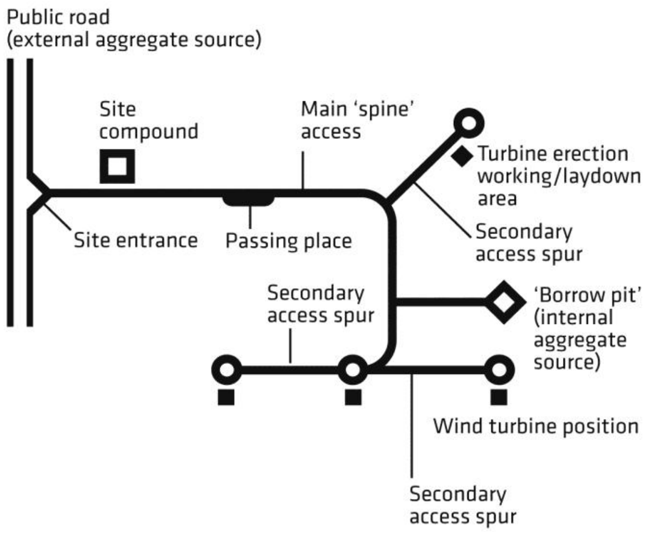

Figure 1: Schematic of the salient features of a wind farm layout

The primary function of these roads is to provide safe, reliable access for materials, turbine components and the passage of cranes to the turbine locations. However, the most intense traffic is usually the aggregate delivery vehicles which are utilised in the road construction itself.

The only type of access road that can be constructed over peat, with a finite quantity of fill material and brought into immediate service, is often called a 'floating road'. In reality the road does not float but the construction relies on reaching an equilibrium state between the weight of the stone and the inherent strength of the peat. Peat is a soil that will gain in shear strength as a response to increased stress and the resulting compression and primary consolidation process. The geogrid will create a mechanically stabilised layer to provide the benefit of minimising the road thickness.

Design is entirely empirical. However, with increasing experience of field performance at both construction stage and in-service, it is possible to review the record of completed projects using both biaxial and triaxial geogrids, to inspect recent practices. The ultimate aim is to assess the environmental impact of access road construction by analysing the CO_2e emissions up to and including the installation stage.

2. Current Practices

Good practice guidelines have been published recently which assist practitioners in wind farm development, (The British Wind Energy Association, 1994), (Scottish Renewables, 2010). More specifically, floating roads practices are described in (Scottish Natural Heritage, 2010).

2.1 Fill Material

In early wind farm access road building, 'instant construction' over peat was seen as a challenge involving high risk and a regard for the unknown: both of which placed high reliance on the emerging geogrid technology. A saving grace was that, at least, the project should incorporate a high quality and consistent fill material such as a public highway aggregate sub-base material. This requirement ensured that the fill would have consistent quality, shear strength and was expected to provide optimal interlock with the geogrid apertures. This meant that the fill was normally supplied by an off-site commercial quarry.
A significant trend is that, for many parts of the UK, the project is planned around on-site borrow pits. A corollary of this is that the arisings may be processed on-site to achieve an acceptable grading or, increasingly, to deliver an 'as blasted' material. This can result in a reasonably well graded material, which is important, but as a coarse aggregate providing a maximum particle size of 250 mm and more. Coarse aggregate, containing boulders, has an influence on the design. The bearing capacity, especially a load spread model, will require a sufficient thickness to obtain the inter-particle contact to spread the load to the foundation soil. Undoubtedly, fill quality and source is the main economic driver in both cash and a carbon footprint sense. This latter aspect is examined further in this paper.

2.2 Construction vehicles

The required thickness of the road is most strongly influenced by the traffic activity that has to be supported during the road construction stage and which is engaged in the act of importing the fill for further construction activity along the route. The in-service-traffic generated by the importation of concrete and steel, the delivery of the turbine components and the passage of the turbine erection crane is usually a design check on bearing capacity and edge stability rather than the principal determinant of the designed thickness. There is a trend for the payload of the fill importation vehicles to increase over time. Early activity saw fill being delivered in 20 tonnes payload road-going vehicles delivering fill from a local commercial quarry. With the advent of borrow pits, earthmoving dump truck vehicles are more commonly used with a payload of 35 tonnes, or more. It is the axle loading which has a strong influence on design and the reduced number of vehicle movements only partially counteracts the influence of the vehicle payload and axle load.

2.3 Crane travelling weight

As the turbine capacity and unit weight has increased then so too has the required lifting capacity and travelling weight of the crane. The early activity saw crawler cranes being sufficient with a travelling weight of around 30 tonnes. Present day cranes can have a travelling weight of at least 100 tonnes and crawler cranes of more than 250 tonnes have been accommodated. The track, or wheel, pressure has not increased at the same rate but it does mean that the road width, vehicle eccentricity to the road centre line and edge stability are increasingly more important design checks. The positioning of the crane with respect to the access road centre-line, (as permitted by a site operational plan), means that edge stability considerations have shifted the road width dimension from being a design input to a design output. So, no longer is a road width adjusted solely to accommodate setting out geometry, (e.g. the sweep of a long wheelbase trailer), but now includes the permitted positioning of the wheel or tracks of the erecting crane. For this reason, a recent trend has been the need to identify, and commit to, the crane type at an earlier stage in planning and preliminary design.

2.4 Bespoke Design

For design purposes, even though there are many classifications for peat, the strength property, ex-pressed as a California Bearing Ratio, is commonly quoted in the range 0.5% to 1.0%. This is a small range in itself but each end of this range produces substantially different thicknesses for a mechanically stabilised layer in the road design. The designer needs to draw therefore on experience of the performance of roads which have been constructed over the last twenty five years. If the subgrade strength is uniformly low on a site, then considerable economies, (cash and carbon), can be derived by evaluating the construction traffic requirements of the spine and spur roads which commonly make up a typical site. Performing a bespoke design, tailoring road sections to the traffic to be carried by them, is a recent trend in refining detailed design and making further marginal savings in both cash and carbon.

2.5 Road Thickness

Attention has drawn away from whether a road is able to be constructed in the first place and whether it can then support the in-service traffic to, nowadays, 'How thick does it have to be/ how thin can it be made?' There are conflicting influences on the thickness of the access roads. These include:

- the coarseness of fill, which leads to thicker roads,
- the lower quality of the fill, which leads to thicker roads,
- the extent of the wind farm road network which leads to thicker roads, (in places),
- the in-service traffic increase, (e.g. the travelling weight of the crane), which may lead to thicker roads,
- the level of confidence in the adopted design method to be able to respond to commercial drive to lower the construction cost, which leads to thinner access roads,
- The development of geogrids with improved stabilisation properties, which leads to thinner access roads.

Figure 1 has been modified to indicate, in Figure 2 a representation of the road construction thicknesses ascribed to different sections of road.

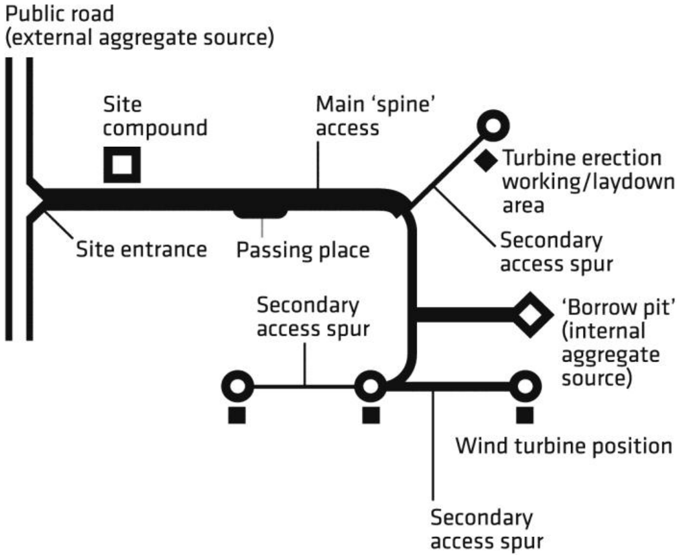

Figure 2: Schematic of road thickness, denser lines indicate a higher construction traffic design load

Figure 2 shows how an analysis of the traffic use can lead to a site-specific 'bespoke design' rather than applying a common thickness to the whole of the project. The first task is to provide an access to the borrow pit and then service the road construction activity from that source of aggregate.

3. Environmental Impact and the 'Carbon Footprint'

As wind farm development is a response for cleaner forms of renewable energy, then the developers tend to have similar policies which place demands on their service providers and supply chain supporters. The construction of access roads can contribute to this effort by making a process map, evaluating the energy absorbing activities and assessing the emissions in terms of carbon dioxide equivalent gases.
A record of UK and Ireland wind farm projects has been maintained over the period 2002 to 2011. Those projects carried out over a peat subgrade, have provided data which can be analysed for the carbon footprint. The analysis, the process mapping, is summarised as the embodied carbon within construction materials at their 'factory gate' through delivery and then up to the completion of construction of the

access roads. The process map is taken up to construction, as depicted by the vertical line in Figure 3: it is part-way through the whole life assessment. It can be seen that there are two streams leading up to the site activities – the quarrying activity and the geogrid manufacture.

The calculation process and the sources of data give rise to the process mapping, (Belton 2010), shown in Figure 3.

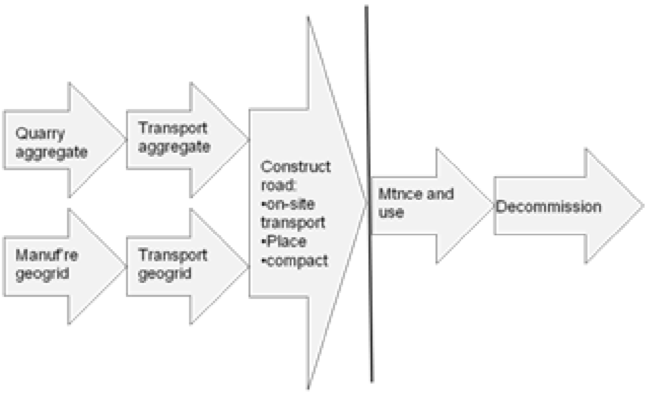

Figure 3: Process map for calculating embodied carbon

Various analyses have been performed in this way to investigate trends and to examine whether common themes or guidelines can be extracted.

3.1 Thickness v Time

Figure 4 is a plot of the site average access road construction thickness plotted against the year of construction.

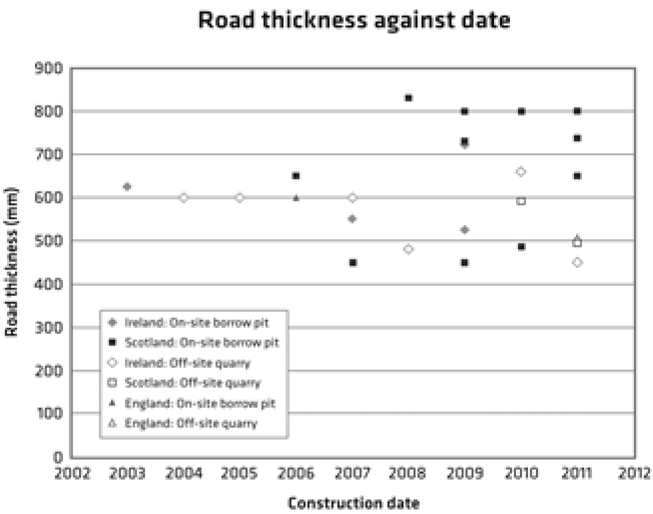

Figure 4: Road thickness v construction date

This plot shows no strong trends in the thickness of roads being constructed. The authors expected the data to show a small decrease in thickness, (post-2006, at least), as feedback from successful installations and growing confidence in the design methods increased. However, there are two contra-acting trends of wind farm road networks becoming more extensive and also the increased loading from the in-service traffic.

3.2 Thickness v Importation distance of the fill

Figure 5 is a plot of the thickness of the access road against the distance from the fill source. The source is either an on-site borrow pit of an external quarry.

Much of the data is clustered around the on-site borrow pits and their relatively short haul distances. Given that road thickness is a function of construction traffic activity, the fill delivered from an external source appears to traffic the road network to a lesser amount and roads tend to be marginally thinner.

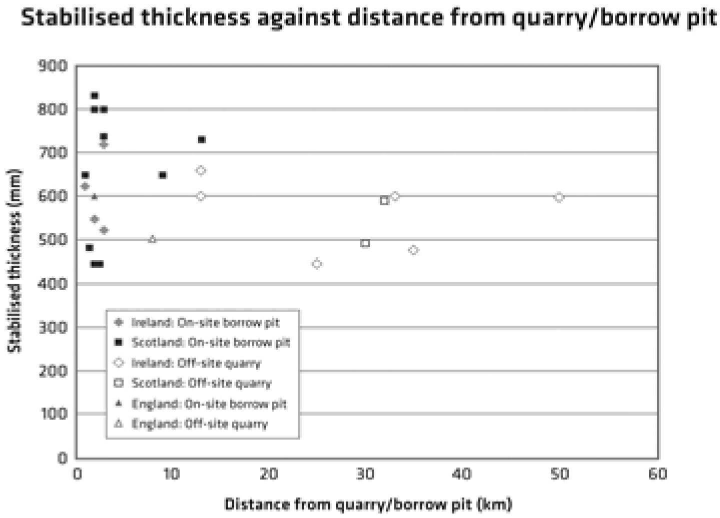

Figure 5: Road thickness v distance from aggregate source

3.3 Carbon emissions & access road thickness

Figure 6 is a plot of the carbon footprint, measured as CO_2e emissions per square metre of construction, against access road thickness. This shows the expected increasing trend as the individual sites possess their own demand on access road thickness requirements. It can be seen that a 'carbon footprint' figure for wind farms over peat is around 10 kgCO_2e/m^2 of construction. As a baseline, the data suggest that a minimum guideline figure for estimating CO_2e emissions is 1.3 kgCO_2e/m^2 of construction/100mm of construction thickness.

The mean of the data set is 1.55 $kgCO_2e/m^2$/100 mm of construction thickness. The range of values is from 1.3 to 2.1 $kgCO_2e/m^2$ of construction/100mm thickness. The lower end of the range is characteristic of on-site borrow pits. The upper end of the range is characteristic of distant external quarry sources.

The data suggests that the trends are similar for England, Scotland, (predominantly blanket peat) and Ireland, (fenland, raised and blanket peat).

As a further aid to estimating access road requirements, then preliminary estimates can be made knowing that the thickness is unlikely to be less than 450 mm. The data has a spread with a mean thickness of 615 mm and a standard deviation of 120 mm.

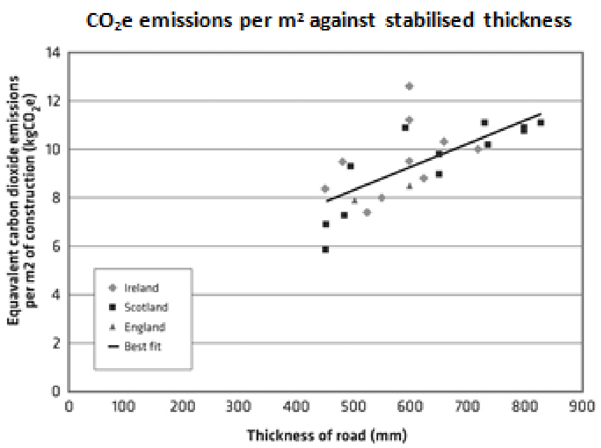

Figure 6: Carbon footprint v road thickness

3.4 Carbon emissions v Distance from fill source

Figure 7 is a plot of the carbon footprint against distance to the fill source. The distribution of carbon emissions accord with Figure 5 but now show that the more distant off-site quarry sources pay a carbon penalty and can increase a typical on-site borrow pit value of 8 $kgCO_2e/m^2$ of construction to 10 – 12 $kgCO_2e/m^2$ of construction.

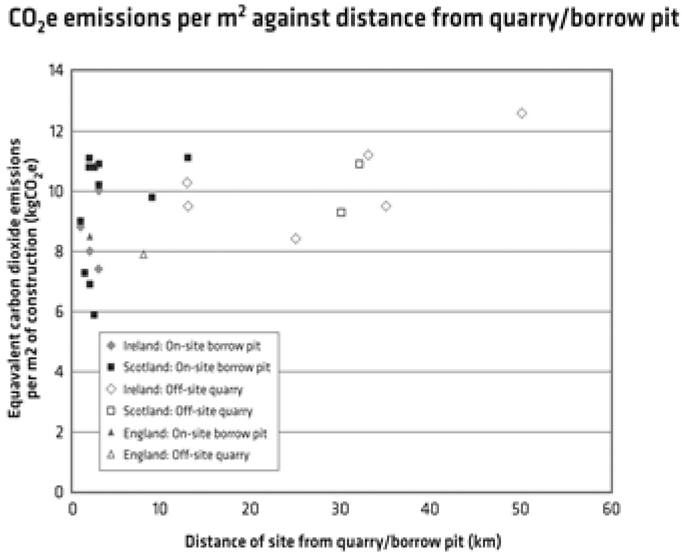

Figure 7: Carbon footprint v distance from fill source

3.5 Carbon emissions analysis

From Figure 6, there are some projects which fit on, or very close to, the line of best fit. These can be analyses to examine the average values of various components of the carbon footprint, as shown in Figure 8.

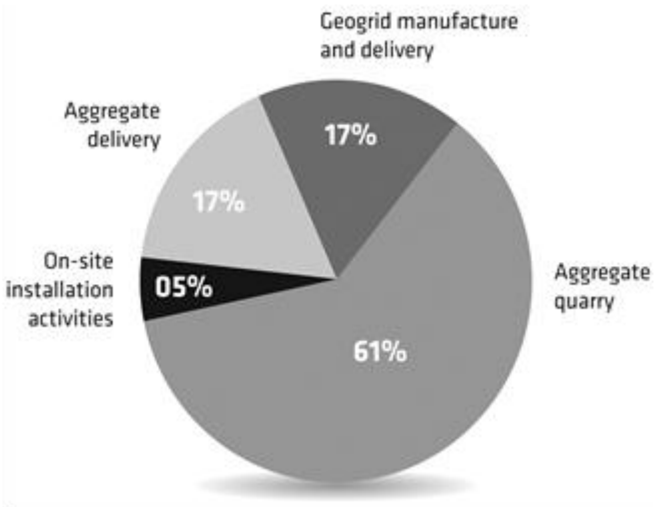

Figure 8: Analysis of the carbon footprint components

It can be seen that the dominant activity is quarrying, accounting for 61% of emissions produced to bring the aggregate to the quarry 'factory gate'. The aggregate delivery typically accounts for 17% of the total but within this figure lies the greatest variation. Off-site aggregate sources can increase this figure to around 33% whereas on-site borrow pits bring the figure down to around 8%. The geogrid manufacture and delivery to site will account for around 17% of the total emissions. The on-site activity of spreading, leveling and compaction is relatively small at 5%.

4. Conclusions

This unique record of 'floating roads' over peat in the UK and Ireland has presented an opportunity to examine practices and trends – particularly with respect to the carbon emissions associated with their construction, (kg CO_2e/m^2 of construction).

1. The practice of floating road construction is now well established

2. Fill materials are normally derived from on-site borrow pits and their grading is becoming coarser and the quality is becoming poorer

3. As the turbine equipment becomes larger, the influence of the travelling weight of the crane is increasing with the need for more rigorous bearing capacity and edge stability checks

4. The data set provides the following indicators:

   a. A conservative estimate of the carbon footprint is 1.3 $kgCO_2e/m^2$ of construction/100mm
   b. The mean value of the data set is 1.55 $kgCO_2e/m^2$ of construction/100mm thickness
   c. The range of values in the data set is from 1.3 to 2.1 $kgCO_2e/m^2$ of construction/100mm thickness
   d. The lower end of the range, in 'c' is characteristic of on-site borrow pits
   e. The upper end of the range in 'c' is characteristic of distant external quarry sources

5 The mean thickness of a floating road over peat in the wind farm data set is 615 mm and the standard deviation is 120 mm.

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