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Potential Savings in Carbon Dioxide Emissions by Using Geogrid Reinforcement in Unbound Roads

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ABSTRACT

Geogrids are commonly used to enhance the performance of aggregates in unbound roads such that a lesser thickness of aggregate is required to achieve the same performance criteria. The benefits of using geogrids in ground stabilisation works can be assessed in terms of the value added to a project: shortened construction programme; reduced overall costs; innovative solutions. Further value may be added by consideration of carbon dioxide emissions. Carbon dioxide emissions are becoming increasingly important in the assessment of the sustainability of projects and clients, regulators and funders are increasingly asking for ‘carbon footprint’ information. The authors have developed a carbon calculator, believed to be the first in the sector, to assess the potential percentage carbon saving available by using geogrid reinforcement in ground stabilisation works when compared with the construction of alternative unreinforced designs. This paper describes the basis of the carbon calculator, clearly identifying the boundaries of the calculation. The relationships between use of geogrid and carbon dioxide emissions are explored and the potential for realising significant reductions in carbon dioxide emissions by using geogrid ground stabilisation in place of traditional unreinforced aggregate road construction is introduced. For some projects construction of an unbound road network on very poor ground, such as at wind farms, may be a critical element of the whole development. Any reductions associated with road construction will have a significant contribution to whole project reductions. Short case studies are presented for some recent projects to demonstrate the magnitude of potential carbon reductions available.

1. INTRODUCTION

It is becoming increasingly important for businesses to be aware of the contribution they are making to global carbon dioxide (CO_2) emissions. The carbon dioxide and other greenhouse gas emissions for which an individual, an organisation or an activity is responsible are often referred to as the ‘carbon footprint’ of that individual, organisation or activity. Total emissions are typically measured in ‘equivalent kg of CO_2’. The call to measure and reduce carbon dioxide emissions is coming from two directions: regulatory and commercial. Regulatory pressures arise from government drives to reduce greenhouse gas emissions in the UK to comply with the Kyoto Protocol. Commercial pressures arise from increased client demand for information to demonstrate steps taken to limit carbon emissions.

The UK is providing a lead in terms of making information about the assessment of carbon emissions publicly available. There are a number of databases of conversion factors for greenhouse gas emissions to equivalent carbon dioxide emissions. A number of tools have also been developed for estimating carbon dioxide emissions from businesses, activities or projects. These calculators tend to be fairly high level and based on a series of generic assumptions. The contribution of a specific product to greenhouse gas emissions can also be assessed from raw materials through manufacturing and distribution to use (Carbon Trust, 2008). Consideration of specific products and activities within a larger project encourages reduction in carbon emissions across the project as a whole.

The authors have developed a carbon calculator, believed to be the first in the geosynthetics sector, to assess the potential percentage saving in carbon dioxide emissions available by using geogrid reinforcement in ground stabilisation works when compared with the construction of alternative unreinforced designs. For the purposes of this paper, geogrid is defined here as, ‘a planar, polymeric structure consisting of a regular open network of integrally connected tensile elements, which may be linked by extrusion, bonding or interlacing, whose openings are larger than the constituents, used in contact with soil/rock and/or any other geotechnical material in civil engineering applications' (IGS 1996).

The majority of construction projects require either temporary or permanent roads to allow access to, from and around the site. Traditionally access roads are constructed using a volume of aggregate material appropriate for the anticipated ground conditions and expected traffic loading. There are significant carbon dioxide emissions associated with the use of aggregate from extraction at the quarry, though transportation to site to compaction during construction (The Waste and Resources Action Programme [WRAP] 2008). Using geogrid reinforcement for ground stabilisation allows a reduced thickness of an unbound road construction, and therefore the mass of aggregate to be extracted. This in turn reduces the volume of aggregate quarried and reduces the number of vehicles required to deliver material to site. These benefits can be assessed in terms of the value added to a project: shortened construction programme, reduced overall costs, and innovative solutions. The carbon calculator described here estimates the additional benefits these savings have on carbon dioxide emissions, taking into account carbon emissions associated with the manufacture and delivery of geogrid.

2. BASIS OF CALCULATOR

2.1 Industry Guidance

The carbon calculator has been developed in accordance with the 'Carbon Trust Measurement Methodology' (Carbon Trust, 2007b). PAS 2050, 'Specification for the assessment of the life cycle greenhouse gas emissions of goods and services' (2008) incorporates and supersedes the Carbon Trust Methodology and the calculator is maintained in accordance with this document. PAS 2050, and the accompanying 'Guide to PAS 2050' (2008) give current best practice for calculating the carbon dioxide emissions associated with specific products or services.

While the carbon calculator is based on current industry guidance, it has been developed for an application of a specific geogrid product. Product and site specific data are duly incorporated into the calculation.

2.2 Design of the Carbon Calculator

2.2.1 General

The Guide to PAS 2050 (2008) gives five basic steps to calculating the 'carbon footprint' of a product:

- Building a process map
- Checking boundaries and prioritisation
- Collecting data
- Calculating the footprint
- Checking uncertainty

The development of the carbon calculator follows these steps for geogrid reinforcement in unbound roads. The following sections describe the approach adopted for each.

2.2.2 Building a Process Map

The basic process map for ground stabilisation is shown in Figure 1. Each of the stages that make up the process is further divided into a number of sub-processes which may be associated with materials, plant or energy consumption.

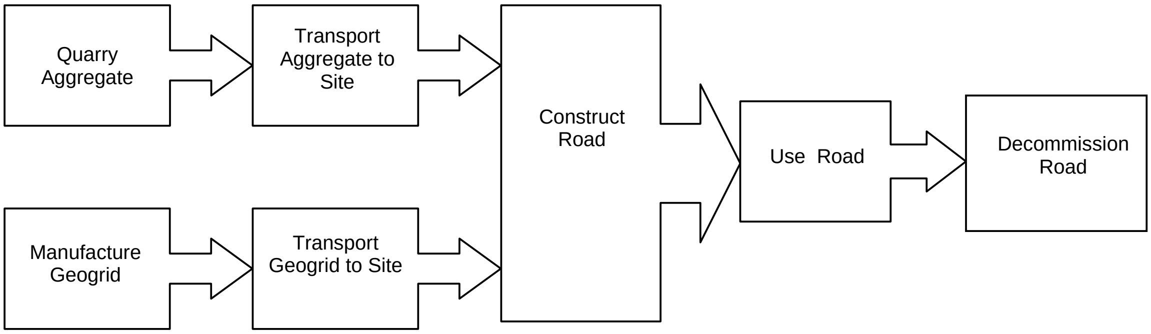

Figure 1. Process Map for geogrid-reinforced ground stabilisation

2.2.3 Checking Boundaries and Prioritisation

It is important when communicating carbon dioxide emissions that the boundaries of the calculation are known. Comparison of carbon dioxide emissions for different products can only be made if they are based within a similar set of boundaries.

For the construction of unbound roads, it was considered that the start boundary should be the embodied carbon within the materials used, which is the equivalent carbon dioxide that has been emitted due to the extraction or manufacture of the construction material. This is known as ‘factory gate’ carbon emissions. For aggregate this includes emissions associated with the excavation of the rock. For geogrid this includes emissions associated with the refinement of the raw polymer as well as manufacture of the geogrid.

The end boundary for the carbon calculator is taken as the end of construction of the road.

It is considered that the boundaries given above allow comparison of the carbon emissions associated with construction of unreinforced and geogrid-reinforced roads. The alternative unreinforced designs used for the analyses have the same performance specification such that it is considered appropriate to bound the process at the end of construction. Further studies based on trafficking, maintenance cycles and decommissioning may investigate additional benefits.

2.2.4 Collecting Data

Published carbon dioxide emissions and correlations relating fuel efficiencies for various fuel types to carbon dioxide emissions are taken from Defra sources (2005, 2007 and 2008).

The embodied energy of quarried aggregate was taken from the University of Bath Inventory of Carbon and Energy (2008).

Carbon emissions associated with construction of the access road, including transportation and compaction, were taken from WRAP Aggregain (2006).

Product specific data were also collected from the raw material supplier and the geogrid manufacturing plant itself.

Table 1 shows the publicly available data used by the carbon calculator.

Table 1. Source Data used in Calculation

Item	Value	Unit	Data Source
Material Embodied CO2			
Polypropylene	2	kgCO2/kg	Plasticseurope 100yr equivalent
Natural Aggregate	0.005	kgCO2/kg	University of Bath ICE
Energy Embodied CO2			
Grid Electricity	0.43	kgCO2/kWh	Defra 2008 long term
Natural Gas	0.206	kgCO2/kWh	Defra 2008 net cv
Diesal Embodied CO2	2.6304	kgCO2/litre	Defra 2008 net cv
Road Transportation Embodied CO2			
Fully Laden Truck	1.008	kgCO2/km	Defra 2008 arctic lorry >3.5-33t
Empty Truck	0.672	kgCO2/km	Defra 2008 arctic lorry >3.5-33t
Sea Transportation Embodied CO2			
Transport by container ship	0.00897	kgCO2/tonne payload/km	WRAP Aggregain
Natural Aggregate			
Density Quarried Natural Aggregate	2.1	t/m3	WRAP Aggregain
Aggregate Truck Capacity	25	t	Assumed value
Construction Processes			
Layer Thickness	150	mm	HA SHW table 6/1 and 6/4
Compaction	0.0496	kgCO2/m2	WRAP Aggregain

2.2.5 Calculating the Footprint

The manufacture, design and construction of a specific geogrid have been considered rather than relying on generic assumptions and actual measurements of electricity consumption have been taken instead of using estimated values. The carbon calculator is maintained by the authors and is routinely modified in line with updates to the published data relied upon.

The carbon calculator is not a primary design tool. It has been developed to complement an “application suggestion”, (suggested use of geogrid for a specific application, provided by the manufacturer), with information on the potential reduction in carbon dioxide emissions associated with reinforced ground stabilisation solutions when compared with non-reinforced solutions. The calculator requires the following input parameters:

- Reinforced thickness
- Distance to UK site from geogrid factory
- Plan area of unbound road
- Strength of subsoil (California Bearing Ratio (CBR) value)
- Number of layers of geogrid required
- Distance to the site from the quarried aggregate source

The carbon calculator uses these site specific data along with the embedded source data discussed above to estimate carbon dioxide emissions associated with each sub-process of the construction of reinforced and un-reinforced roads. Figure 2 shows a flow chart for the calculation of carbon dioxide emissions associated with delivery of geogrid from the factory to site, being just one of the sub-processes involved.

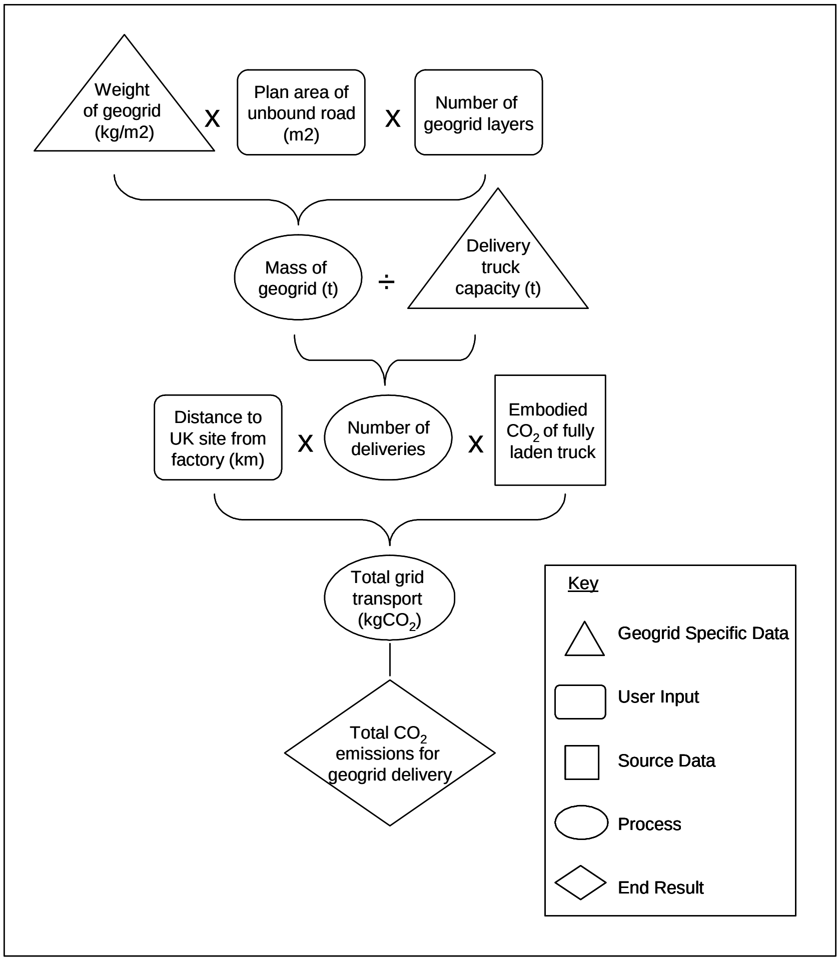

Figure 2. Calculation Process for Total CO_2 Emissions for Geogrid Delivery

Total carbon dioxide emissions to the end of construction are calculated for both reinforced and equivalent non-reinforced solutions and the percentage difference is presented. A pie chart is created which gives a breakdown of the contributions of each process of ground stabilisation (reduced volume of aggregate, reduced transportation of materials and reduced compactive effort) to the total reduction in carbon dioxide emissions for the reinforced road compared to an equivalent unreinforced road. The calculation takes into account the additional carbon dioxide emissions associated with the geogrid for the reinforced option, which are found to be minimal compared with the reductions in emissions associated with the reduced volume of aggregate required.

2.2.6 Uncertainty

Assessing the uncertainty of carbon calculations is not prescribed in PAS 2050 (2008) but the Guide to PAS 2050 (2008) recognises that best practice in product carbon footprinting aims to minimise uncertainties to help provide more robust, reliable and replicable results. Uncertainties in the carbon calculator developed by the authors are reduced by the use of primary activity data and maintenance of the calculator.

3. POTENTIAL CARBON REDUCTIONS

The potential reductions in carbon dioxide emissions available by using geogrid reinforcement in unbound roads have been investigated by the authors by means of a number of example scenarios. For each case the geosystem (a generic term for a composite working system in the ground which includes engineering input, soil and geo-components, (Belton et al, 2008)) has been designed and the carbon calculator has been used in accordance with the application suggestion to estimate the potential carbon savings available. It is noted that the geosystem designs are specific to the geogrid and ground conditions assumed and the trend lines presented below are indicative and should not be used for design.

Figure 3 shows the trend of potential carbon reductions against CBR. The thickness of aggregate required to stabilise soft ground (say CBR = 0.5) is greater than that required to stabilise firmer ground (say CBR = 3). Geogrid reinforced unbound roads are necessarily designed with a discreet number of layers (typically 1 to 3) of geogrid. The efficiency of the geosystem increases with the thickness of aggregate reinforced with a certain number of layers of geogrid. There is a maximum thickness of aggregate that is appropriately reinforced by each layer of geogrid. This provides a saw tooth profile of efficiency and therefore the variation of potential carbon reductions with CBR is not linear.

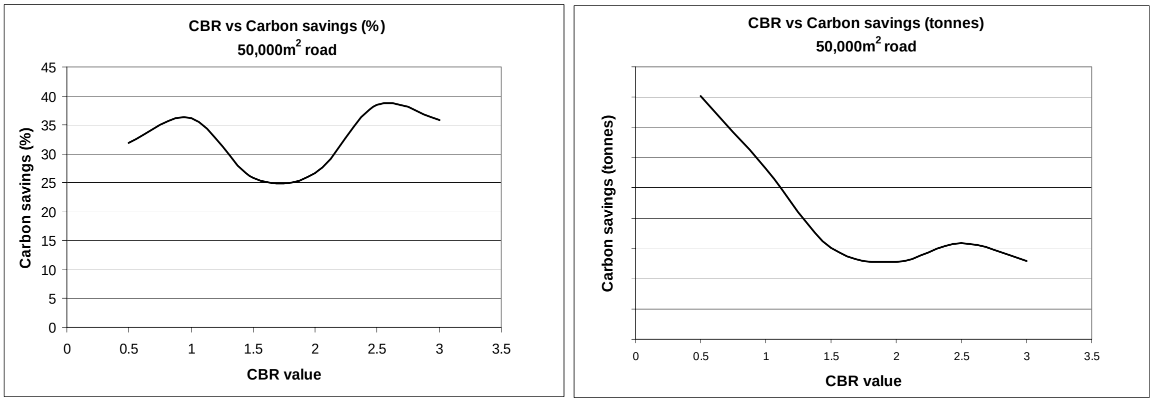

Figure 3. Potential reduction in carbon dioxide emissions against CBR value

Figure 4 shows the trend of potential carbon reductions against distance from site to the natural aggregate quarry. Reductions in carbon dioxide emissions associated with the distance to aggregate source are primarily due to transportation of a lesser volume of aggregate from the site for the reinforced construction.

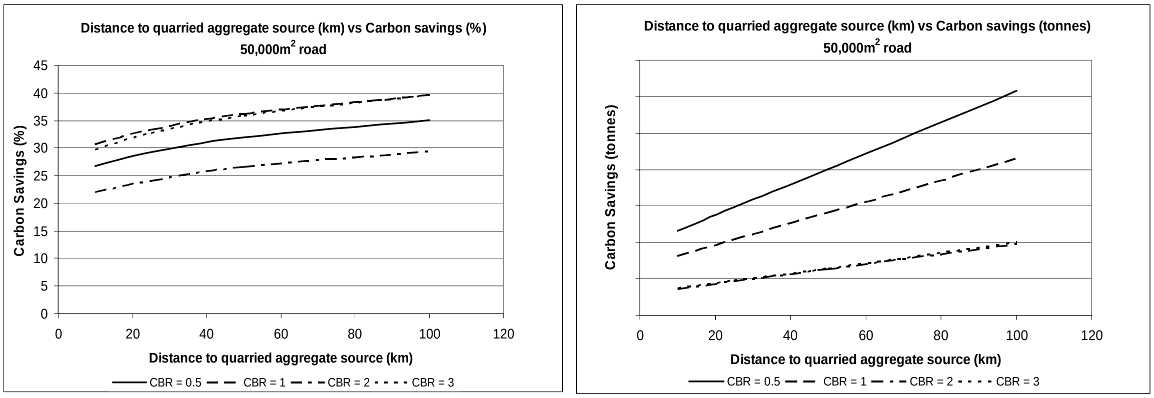

Figure 4. Potential reductions in carbon dioxide emissions against distance to aggregate source

Figure 5 shows the trend of potential carbon reductions against plan area of the ground to be reinforced. In the UK design loadings for roads are based on the number of 'standard axles', a standard axle being the equivalent of a single commercial vehicle with a weight of 8,200kg making one pass over the road. The relationships presented here are based on temporary access roads, where traffic for construction of the road itself often provides the maximum loading. The number of standard axles for which the road is designed therefore increases with road plan area. While the magnitude of potential carbon savings consistently increases with road plan area, the percentage carbon savings shows the non-linear effects of geogrid design efficiencies

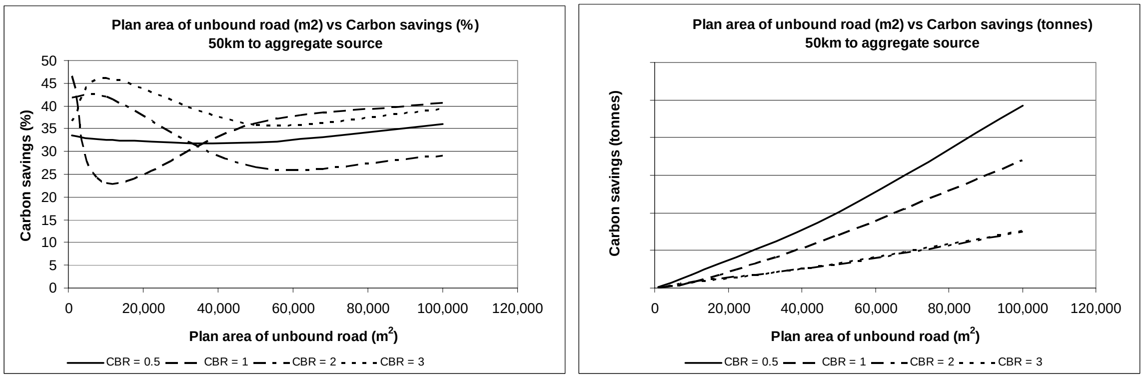

Figure 5. Potential reductions in carbon dioxide emissions against plan area

4. CASE HISTORIES

4.1 Hotel car park and access roads

A permanent car park, access routes and a temporary working platform for a 135 tonne crawler crane were needed for a Hotel in the north of England. From the site investigation it was identified that the subgrade was of variable strength and that a minimum CBR value of 5% was required. During construction CBR values in the range 1.0% to 2.7% were encountered and an access road of 250mm of coarse aggregate that was installed over a separating geotextile did not perform as required under construction traffic.

To accommodate the lower CBR values the earthworks design was revised to include geogrid reinforced ground stabilisation. The reinforced solution required over 40% less fill than a traditional unreinforced aggregate layer. A 380mm thick aggregate layer incorporating 2 layers of geogrid was constructed to form the car park and access roads. The double geogrid layer provided the additional benefit of providing flexural stiffness, helping to control differential settlement over the variable subgrade.

On completion of the project, it was possible to review the energy consumption arising from all the activities – from quarrying through to compaction. The carbon calculator was used to compare the installed solution with the alternative unreinforced design option. The result showed that the installed section provided a significant 29% reduction in carbon dioxide emissions compared with the equivalent unreinforced section. Figure 6 gives a breakdown of the contributions of each process of ground stabilisation to the total reduction in carbon dioxide emissions.

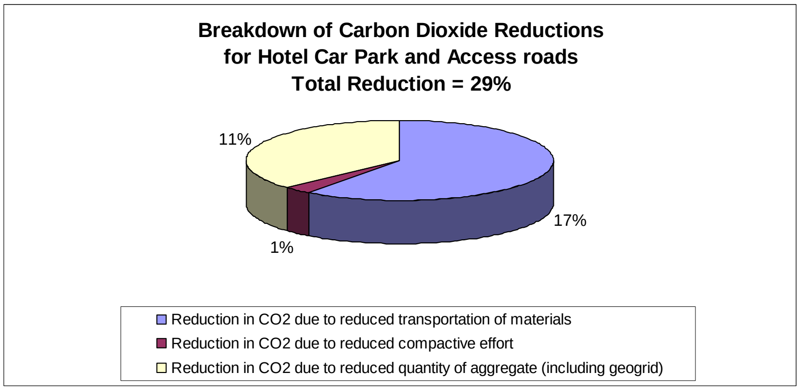

Figure 6. Potential reductions in carbon dioxide emissions for hotel car park and access roads

4.2 Wind Farm, Scotland

Peat and other weak soils are frequently encountered on wind farm sites. The most common methods available for creating site roads on weak ground are to ‘punch-in’ bulk fill until a sufficient bearing capacity is achieved and to construct geogrid reinforced floating roads, that is geogrid reinforced aggregate layers that sit on top of the soft peat.

This wind farm project offered the opportunity to compare the carbon dioxide emissions associated with a geogrid stabilised design against the alternative traditional bulk fill option. The saving in aggregate volume is greater for reinforced floating roads over peat than for reinforced roads over more competent ground as the traditional method requires additional aggregate to be ‘punched’ into the very soft peat. The carbon calculator could not be used directly to estimate the carbon savings achieved by adopting a reinforced floating road for access roads on the site as it would have given a conservative estimate of carbon savings. A carbon saving calculation based on actual aggregate savings estimated that the installation of a floating road provided a significant 35% reduction in carbon dioxide emissions compared with the equivalent bulk fill approach. Figure 7 gives a breakdown of the contributions of each process of ground stabilisation to the total reduction in carbon dioxide emissions.

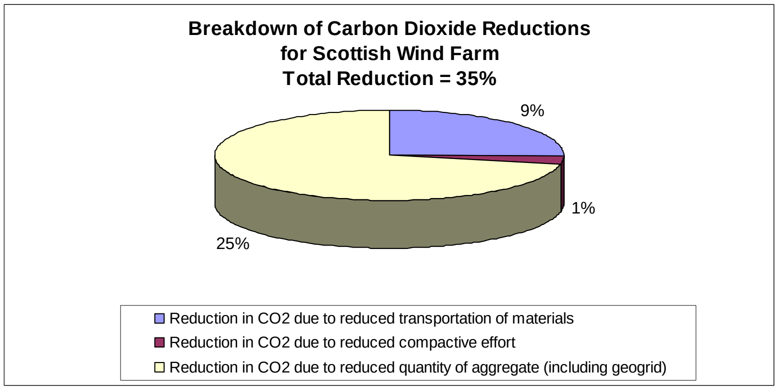

Figure 7. Potential reductions in carbon dioxide emissions for wind farm in Scotland.

5. FURTHER WORK

The current version of the carbon calculator accommodates projects in the UK based on the geogrid being delivered from a UK factory. The calculator is undergoing modifications which will allow it to estimate potential carbon savings of projects in other countries, taking due account of transportation issues.

The specific benefits of reinforced floating access roads over peat are discussed in Section 4.2 above. Further interrogation of wind farm case histories will allow a greater understanding of the potential carbon savings available for work in these areas.

The carbon calculator is currently applicable to unbound roads. Future work will include assessment of carbon savings available by using specific geosystems in place of traditional structures.

6. CONCLUSIONS

The carbon calculator demonstrates that potential carbon savings of up to 50% are available by using geogrid reinforced roads instead of traditional unreinforced constructions. The carbon calculations have clear boundaries and are applicable to a specific geogrid product.

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