Rampion Offshore Wind Farm

ES Section 30 – Carbon Balance

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30.1 Introduction

30.1.1 This section of the Environmental Statement (ES) focuses on an overall carbon balance for the Rampion Offshore Wind Farm (the Project). In this context, ‘carbon’ is referred to as shorthand for greenhouse gases. Although gases having an impact on climate change – the so-called ‘greenhouse gases’ are mostly carbon based (such as CO_2), some are not (such as sulphur hexafluoride (SF_6). The greenhouse gas emissions that will arise during the Project’s lifecycle can be estimated. These include direct emissions that occur during Project construction, operation and decommissioning; and indirect emissions that occur in the manufacture and transport of Project components such as turbines, foundations, cables, etc. These emissions are normalised to the electricity produced over the Project’s life to produce a ‘carbon footprint’ for the Project. The footprint is then compared to the latest equivalent data for the UK grid average generation footprint and thus estimates of the greenhouse gas emissions savings associated with the Project can be assessed.

30.1.2 Although the Project is not yet at a stage where indirect emissions, for example from turbine manufacture, can be specifically quantified because of the relatively early stage of the design, the direct emissions – those over which the Project has a greater degree of control – are estimated. This is an inventorisation exercise and no impact assessment is carried out. The impact on local air quality of emissions from onshore activities only is covered in Section 21 – Air Quality.

30.2 Legislation and Policy Context

30.2.1 The overarching policy context for this section is as described in Section 4 – Policy Context and the need for the Project is discussed in detail in Section 1 – Introduction. In summary, to avoid the adverse consequences of global warming the UK must contribute to efforts to reduce greenhouse gas emissions. The generation of electricity from offshore wind is likely to be a substantial contributor to the UK’s efforts in this area (DECC, 2011).

30.2.2 Because greenhouse gas emissions have a global, rather than local, effect it is important to consider the lifecycle of a project such as Rampion. Also, as an overall increase in power demand may act as a confounding factor, it is important to account for the extent to which greenhouse gas emissions are actually saved (offset) by replacing fossil-fuelled generation, and the amount of the offset claimed (since building the Rampion project will itself result in greenhouse gas emissions). That is the aim of the carbon balance assessment in this section, which has used accepted standard approaches to the calculation of the carbon balance.

30.2.3 The emissions to atmosphere from the vessels that will be used to construct, operate, maintain, inspect and decommission the offshore elements of the Project are governed by the International Maritime Organization's International Convention for the Prevention of Pollution from Ships 1973, as modified by the Protocol of 1978 relating thereto (MARPOL 73/78). In particular, Annex VI sets limits on emissions of nitrogen oxides and sulphur dioxide that have been tightened via revisions as technology has improved. In July 2011, measures were adopted that added a new Chapter 4 to MARPOL Annex VI entitled "Regulations on energy efficiency for ships", making mandatory the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships. These regulations, which aim to reduce the carbon intensity of transport by sea, will apply to all ships over 400 gross tonnage and are expected to enter into force on 1 January 2013.

30.2.4 For the Project's direct onshore greenhouse gas emissions – essentially limited to emissions from the exhausts of road vehicles and non-road construction equipment - the policy and legislation is wide-ranging. Policies act to drive down carbon emissions from this sector through, for instance, encouraging better fuel efficiency, substitution with lower carbon fuel alternatives, and lower emissions. Examples of measures include CO_2 emissions being a mandatory element of vehicle specification and vehicle excise duty being set on the basis of those emissions, measures to promote the use of sustainable biofuels, and rebates on the purchase of electric vehicles. In general, however, market forces such as the price of fuels have played perhaps the greatest role in driving vehicle efficiency improvements over recent years.

30.2.5 This section also considers impacts that occur upstream of the Project, i.e. in the supply chain. It is not possible to detail the legislative and policy context that relates to such impacts as there will be a very wide range of processes and products involved, these might occur anywhere in the world and may be outside the direct control of the Project. Allowance for upstream carbon emissions has however, been included in the carbon balance assessment.

30.3 Assessment Methodology

30.3.1 At this stage of the Project design, many of the specific elements that will result in emissions are not yet defined. For example:

- The wind turbine generator make and model to be used (which, in turn, affects the number to be installed and the location of the supplier amongst many other aspects);
- The foundation design and supply route for the concrete and other materials (i.e. steel); and
- The specific vessels to be used to install, maintain and inspect the facilities.

30.3.2 It is therefore not possible to carry out a full, Project-specific lifecycle inventory that might comply with relevant standards such as ISO 14044, the Greenhouse Gas Protocol Product Standard[1] or the Environmental Product Declaration[2] programme rules. It would not be possible to meet the relevant data quality requirements due to the uncertainties in the Project, as detailed designs are still being developed. Therefore, this carbon balance assessment relies on published literature, whilst also considering Project-specific factors that may influence the literature values.

30.3.3 For the quantification of direct offshore emissions the predicted vessel types, their predicted use and estimated fuel consumption are combined with published emission factors to derive the emissions data. A similar approach is applied to the emissions from onshore construction vehicles and equipment.

30.3.4 There is no establishment of baseline environmental parameters for this section. The baseline relevant to the emission of greenhouse gases is the concentration of these gases in the atmosphere and ultimately, the global climate. It is therefore beyond the scope of this environmental assessment.

30.3.5 For the same reasons, there is no quantitative impact assessment in this section, which comprises an inventorisation of the lifecycle greenhouse gas emissions.

30.4 Consultation

30.4.1 As detailed in Section 5 – EIA Methodology, an extensive programme of engagement has been undertaken with regard to the Project; details of which are provided in the Consultation Report (Document 5.1). This included publication of the Draft ES as part of the Section 42 and Section 48 consultation.

30.4.2 Responses from these activities and from consultation on the Draft ES have been incorporated into this Final ES. All responses are documented in the Consultation Report.

30.5 Carbon Footprint of Offshore Wind Power

30.5.1 Table 30.1 shows details of a number of studies on the carbon lifecycle of wind energy projects.

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[1] The greenhouse gas protocol is a method developed by the World Resources Institute and the World Business Council for Sustainable Development. See [http://www.ghgprotocol.org/]; accessed 26.11.2012.

[2] A standardized lifecycle assessment method based on ISO 14025. See [http://www.environmentalproductdeclarations.com/]; accessed 26.11.2012.

Table 30.1: Carbon Lifecycle Analysis of Wind Farms – Literature Review

Source	Installation studied	Study boundaries	Findings
White, 2006	Three onshore wind farms in midwest USA. (i) 73 x 0.34MW (ii) 143 x 0.75MW (iii) 2 x 0.6MW	Full lifecycle, though downstream (transmission and distribution) excluded. Disposal of equipment at end of life also apparently excluded.	CO_2 lifecycle footprint of generated electricity as follows: (i) 14gCO_2/kWh (ii) 18gCO_2/kWh (iii) 34gCO_2/kWh
Martinez *et al.*, 2009	1 x 2MW turbine at an onshore wind farm in Spain	Full lifecycle, though downstream (transmission and distribution) excluded.	Global warming potential - payback time of 94 days
Ghenai, 2012	1 x 2MW turbine, onshore, non-specific location	Full lifecycle, relies to a substantial degree on Martinez *et al.*	CO_2 lifecycle footprint of generated electricity as follows: If turbine landfilled: 8gCO_2/kWh If turbine recycled: 5gCO_2/kWh
Vestas, 2006	100 x 3MW Vestas V90-3.0 offshore and onshore	Full lifecycle, includes all offshore cabling and transformer stations and onshore substation. Excludes downstream losses	CO_2 lifecycle footprint of generated electricity as follows: Offshore: 5.2gCO_2/kWh Onshore: 4.6gCO_2/kWh
Jungbluth *et al.*, 2005	1 x 2MW Bonus turbine, offshore Denmark	Full lifecycle, includes all offshore cabling and transformer stations and onshore substation. Excludes downstream losses	CO_2 lifecycle footprint of generated electricity 13g/kWh
Properzi and Herk-Hansen, 2002	150MW offshore wind farm, Denmark	Full lifecycle, though downstream (transmission and distribution) excluded.	CO_2 lifecycle footprint of generated electricity 3.5g/kWh(1)

(1) Converted from 4 mPE (EDIP methodology), using normalisation reference 1 PE = 8.7t CO_2e/year

30.5.2 While there is a wide range of input parameters, methods and study boundaries that can affect such studies, it is considered that there is a reasonably high degree of agreement among the studies.

30.5.3 The highest normalised carbon footprints (that is, lifecycle greenhouse gas emissions per unit electricity generated) are reported by White, whose study acknowledges that "the wind sites analyzed here are not considered the best wind resources in the US". The wind turbines considered in that study were also the oldest of those studied in the above range of life cycle analyses. In particular the outlying value of 34g/kWh, from the 2 x 0.6MW Glenmore wind farm, is perhaps not surprising given that Glenmore is an "experimental" wind farm, installed to test turbines, where perhaps efficiency driven by commercial factors would not be a factor and efficiencies of scale are not available for such a small facility. Also, by excluding the final disposal of equipment, White omitted an element (component recycling) that would reduce the footprint of the electricity. The effect of recycling is discussed further in paragraph 30.5.6 below.

30.5.4 Of the above studies, the most representative of the Project is the Vestas study, as it is the largest overall (300MW installed capacity), uses the largest capacity turbines (3MW) and is in an offshore location. By studying the same configuration in both an on- and offshore deployment, this study also provides a like-for-like comparison of the effect of siting the facility on- or offshore. It can be seen that Vestas found that the offshore facility had a slightly higher carbon footprint than the equivalent onshore facility, but Flanagan (2010) notes that the literature is in some disagreement here. Jungbluth *et al.* (2005) are in agreement with Vestas, showing carbon lifecycle emissions per unit generated for an onshore plant to be approximately 85 to 90% of those of an offshore plant, but Properzi and Herk-Hansen (2002) estimated the offshore siting to be substantially better in this regard (unlike Vestas, neither Jungbluth nor Properzi examined a like-for-like comparison of turbine / overall installation capacity). Flanagan notes that while offshore units tend to be larger scale with higher site capacity factors, offshore units can involve larger foundation materials, more complex installation and shorter part lifetimes.

30.5.5 A critical aspect on which the studies agree is that the manufacturing phase of the lifecycle dominates its footprint. Vestas evaluates its contribution to be around 95% of the lifecycle gross emissions ('gross' meaning that the beneficial contribution of the disposal phase, as discussed in the next paragraph, is ignored). The transport and operational phases of the lifecycle make up the remainder and thus are relatively insignificant. Jungbluth *et al.* split the lifecycle further and evaluate the contribution of each phase to overall lifecycle CO_2 emissions of the 2MW offshore turbine as follows (values are read from their Figure 8 and thus are approximate): operation 1%, material manufacturing 83%, material processing 5%, assembly and installation 4%, transport 3%, waste disposal 4%. Vestas notes that "it is primarily the extraction of iron ore for the production of steel components and the casting of these that impacts the environment".

30.5.6 The literature is also in general agreement that, because a high proportion of the wind farm can be recycled, the disposal phase of the project lifecycle contributes to the carbon lifecycle by reducing the footprint. The majority of studies are based on most of the turbine components being recyclable or reusable. Vestas claims that 80% of a V90-3.0 MW offshore turbine can be recycled. Most lifecycle inventory analysis methods allow for 'credit' to be given to a project lifecycle in these cases, since recycling material means that the impacts associated with the extraction and processing of virgin material are largely avoided. In their study of the 300MW offshore wind farm, for example, Vestas evaluate that the 'disposal' phase offsets around 30% of the negative emissions resulting from the manufacturing, transport and operational phases. Ghenai finds similarly – he estimates that recycling rather than landfilling reduces the footprint of the 'end of life' phase of the lifecycle of the 2MW onshore turbine from a 13tCO_2 emission to a 496tCO_2 net saving. This has a substantial effect on the overall lifecycle emissions.

30.5.7 The latest available carbon footprint of UK grid electricity, as published in DEFRA's 2012 reporting guidelines is **547gCO_2e/kWh**. This figure:

- Is calculated on a 5-year rolling average basis for 2006 to 2010;
- Includes the indirect emissions associated with primary fuel extraction and transport,
- Excludes losses in transmission and distribution (as do the wind lifecycle studies); and
- Accounts for the proportion of imported electricity.

30.5.8 This figure of 547g/kWh is therefore the most comparable for wind farm studies that include all greenhouse gases and consider the lifecycle of the generated electricity, as opposed to only the direct, on-site emissions associated with the generation. Renewable UK, however, uses a static factor of 430g/kWh to represent the CO_2 emissions from the UK grid electricity mix in calculating emissions savings from wind farms. This is the method used in Section 1 of this ES. Use of the static factor enables like-for-like comparisons of different wind farms over time. In Renewable UK's standard calculation method there is no element of accounting for emissions from the specific wind farm being considered. The figure of 430g/kWh is, however, lower than the grid factor for every individual year from 1990 to 2010 (the latest published year), therefore, it would seem that some allowance for emissions from the wind farm is inbuilt to the Renewable UK factor (e.g. the 5-year average factor for 2006 to 2010 for direct CO_2 emissions only from the grid is 479g/kWh) therefore, in using a factor of 430g/kWh to calculate savings of wind power versus grid power, it is implied that the footprint of the wind farm electricity is 49g/kWh.

30.6 Project-Specific Lifecycle Elements

30.6.1 Figure 30.1 shows the lifecycle stages of a wind farm (offshore or onshore). It is taken from Flanagan (2010).

Material Acquisition, Pre-processing, Manufacturing and Assembly

30.6.2 As discussed earlier in this section, the Project is not yet at a stage where a robust, Project-specific lifecycle can be defined and analysed, as many different elements are still to be finalised. For that reason, no attempt has been made to specifically quantify the emissions from the raw material acquisition and pre-processing and the manufacturing and assembly stages.

30.6.3 For these stages, the Vestas study in particular should be reasonably representative of the Project's emissions. A 3MW turbine is an option for use in the Project, though it is at the lower end in terms of its power output rating of those under consideration.

30.6.4 Higher-rated turbines are larger and hence require more material, entailing more emissions in the raw material extraction and pre-processing stages, but they generate more power, which is factored into the normalised footprint. The weights and materials of a range of turbines under consideration are presented in Table 30.2.

Table 30.2: Wind Turbine Generator Weights and Materials

WTG capacity (MW)	Component mass (tonne)			
	Rotor	Tower	Nacelle	Total
3.0	40	156	68	264
3.6	100	317	125	542
7.0	115	638	390	1143

30.6.5 Table 30.2 shows that wind turbine generator (WTG) mass is broadly proportional to capacity. This does not mean that each WTG type uses the same component materials or that they are present in the same proportions. Furthermore, they are all manufactured at different places in different ways, with differently sourced materials. But, it does perhaps indicate that relying on a near-match, in terms of WTG capacity, to characterise the Project's WTG's footprint may not have a critical effect on the conclusions or their validity.

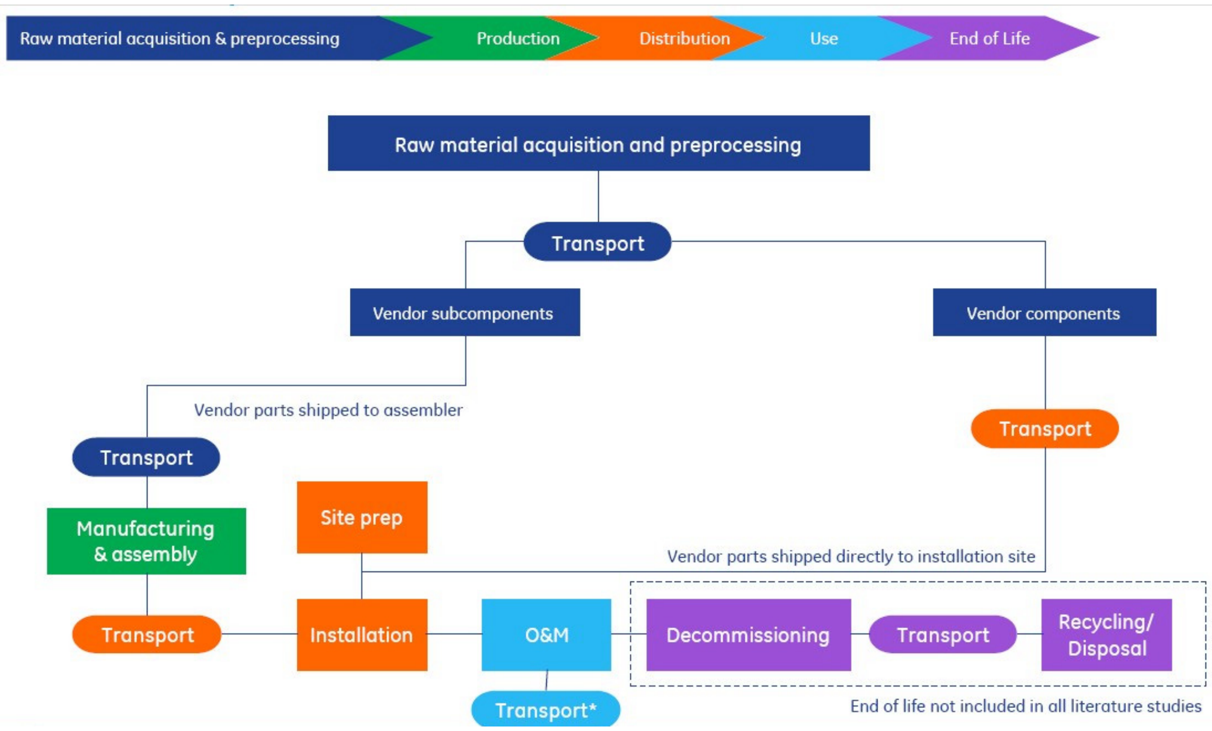

Figure 30.1: Life Cycle of Wind Power

30.6.6 The other main material requirement is for the foundations. Vestas' study was based on monopile foundations, 4m in diameter, inserted 25m into the seabed. The monopile is one of the foundation concepts under consideration for the Project, though it is not likely to be feasible for turbines larger than 6MW capacity. Other foundation types have generally higher masses for the same size of turbine. Foundations are generally made of steel, though gravity base structures can be concrete, steel or a mixture. The Vestas study did not account for any scour protection. In general, therefore, the foundations' contribution to the materials and manufacturing phase of the lifecycle footprint as quantified by Vestas may be underestimated in terms of its representativeness of the Project.

30.6.7 The number of turbines installed may not be critical to the materials' normalised carbon footprint. For this variable it is perhaps possible to be more confident that the relationship between generated power and the WTG materials' and foundations' carbon footprint would be near to linear, resulting in a near-constant normalised footprint, since each turbine would be near to identical. Variations may, however, occur to foundation design with different geological characteristics over the wind farm area. The effect of scale in this regard would be to make the carbon footprint of shared elements (those whose design is not materially dependent on the number of turbines to be installed) such as export cabling and the onshore and offshore substations less significant. A small reduction in the normalised footprint would therefore be expected with increasing installed capacity, but the materials of the turbines and foundations are, according to the published studies, dominant in the overall carbon footprint.

Offshore Direct Emissions – Construction, Operation and Decommissioning

30.6.8 In this section, estimates of the direct emissions of greenhouse gases that will occur due to vessel movements during the construction, operation and dismantling of the wind farm are provided.

30.6.9 Table 30.3 shows a breakdown of the vessel use during the construction phase and the estimated associated fuel consumption.

Table 30.3: Vessel Movements and Associated Fuel Consumption – Construction

Vessel category	Vessel types	Tasks	Estimated total fuel consumption (tonnes)
Heavy vessels	Jack-ups, transport barge, construction barge, rock dumping vessel, crane barge, cable lay vessel, anchor barge, transportation barge	Installation of turbines, foundations, scour protection, offshore substation, array cables and export cables	15,167
Heavy transport vessels	Heavy transport vessel	Inbound supply of cables and foundations from manufacturers, offloading at a local construction marshalling port	2,914
Support vessels	Anchor handling, turbine commissioning, cable burial, survey vessels, diver support vessels, guard vessels, work boat	Anchor handling, turbine commissioning, surveys, cable burials, crew transfer, security, diver support	8,281
			26,362

30.6.10 Table 30.4 shows a breakdown of the vessel movements during the operational phase and the estimated associated fuel consumption.

30.6.11 For the decommissioning phase, fuel consumption is estimated to be 75% of that calculated for the construction phase, since some components e.g. subsurface foundation elements are likely to be left in place.

30.6.12 Table 30.5 shows the calculated emissions when the above fuel consumption data are combined with relevant published emission factors for the greenhouse gases emitted from ship exhausts. The emission factors used were taken from the API Compendium of Greenhouse Gas Estimation Methodologies (API, 2009).

Table 30.4: Vessel Movements and Associated Fuel Consumption – Operation

Vessel type	Tasks	Estimated annual movements during operational period	Estimated fuel consumption per movement (litres)	Estimated total annual fuel consumption (tonnes)
Service vessel	Planned maintenance including cable surveys and foundation inspection every 2 years initially and increasing over time	500	2000	867
Service vessel	Operation and unscheduled maintenance	3000	1000	2602
Jack-up barges with mobile crane or larger special ships	Larger unscheduled maintenance tasks	12	6000	62
				3,531

Table 30.5: Calculated Emissions from Vessels

Lifecycle phase	Estimated fuel use (tonnes)	Estimated greenhouse gas emissions (tonnes)			
		CO_2	CH_4	N_2O	CO_2e[(1)]
Construction	26,363	83,459	5	33	93,536
Operation (per year)	3,532	11,181	1	4	12,531
Decommissioning	19,772	62,594	3	25	70,152

(1) Total greenhouse gases expressed as tonnes carbon dioxide equivalent using global warming potentials over 100 year time horizon from IPCC, 2007.

30.6.13 The contribution to the project's carbon footprint from offshore works is therefore approximately 3.3 gCO_2e/ kWh.

Onshore Direct Emissions – Construction, Operation and Decommissioning

30.6.14 The onshore direct emissions will result primarily from the construction, operation and decommissioning of the onshore cable and the onshore substation. The greenhouse gas emissions associated with each are estimated in Tables 30.6 and 30.7. All estimates are based on the activity levels detailed in Section 2 and estimated rates of fuel consumption.

Table 30.6: Onshore Cable Construction Emissions

Construction element	Estimated fuel consumption (tonnes)	Greenhouse gas emission (tonnes CO_2e)
Site compound	51	163
Trenching	1,929	6,176
Horizontal directional drilling	436	1,395
Material deliveries	167	534
Total	**2,583**	**8,268**

Table 30.7: Onshore Substation Construction Emissions

Construction element	Estimated fuel consumption (tonnes)	Greenhouse gas emission (tonnes CO_2e)
On-site construction equipment	882	2,825
HGV movements to/from site	83	265
Total	**965**	**3,090**

30.6.15 Onshore emissions during the operational phases are discounted as negligible. Emissions during decommissioning are assumed to be 50% of those estimated for the construction phase. Therefore the contribution to the project's carbon footprint from onshore works is therefore approximately 0.3 gCO_2e/ kWh.

End of Life

30.6.16 The end of the Project's life is far into the future. Therefore, attempting to account for the fate of materials, the activity required to physically remove the Project elements and other parts of the end of life phase are subject to significant uncertainty. The standard lifecycle analysis methods and data sources used by the published studies are relied on. The relevant findings are discussed in paragraph 30.5.6.

30.7 Carbon Balance

30.7.1 If it is assumed that the gross normalised footprint (excluding 'credits' for recycling material at the end of life) of the Project's generated electricity will be 15gCO_2e/kWh, which is likely to be a conservatively high estimate given the range of the literature sources detailed above, and its lifetime generation will be 54TWh, based on a 25-year operational lifetime, an installed capacity of 700MW and a capacity factor of 35%, then the overall lifetime carbon footprint of the Project will be 0.8 million tonnes CO_2e.

30.7.2 Using the most comparable grid footprint factor of 547g/kWh (see paragraphs 30.5.7 and 30.5.8), the wind farm saves 532gCO_2e per kWh generated. This means that, after 1.5TWh is generated, the Project will have saved the carbon that was emitted during, and as a result of, its own manufacture and construction and will be emitted throughout its lifecycle, i.e. after adding operation and decommissioning. This generation will be achieved after approximately 2.8% of its operational lifetime, or around 8 months. Using this calculation method, this carbon 'payback period' is independent of the installed capacity of the wind farm and also the capacity factor[3].

30.7.3 In order to make a similar calculation using the Renewable UK standard factor (see paragraph 30.5.8), the assumption of the lifecycle normalised footprint (and hence total lifecycle emission) must be expressed in terms of CO_2 only (not total greenhouse gases). If it is assumed that the footprint value remains at 15g/kWh and the total lifecycle emission therefore remains at 0.8 million tonnes, then the payback period using the Renewable UK emission saving factor of 430g/kWh is increased to 10 months.

30.7.4 After approximately 8-10 months, therefore, the facility is likely to be 'carbon neutral', in that it will have saved the emissions that were created in its inception[4]. In the remainder of its life, it will of course almost certainly continue to save emissions relative to the UK grid mix at that time. At the end of the Project's life, credits may also be applied to this calculation for the recycling or reuse of the materials (an alternative way to account for this would be to include it in the overall normalised footprint, in which case that may be reduced to around 10g/kWh and the payback period would be commensurately shorter).

30.8 Conclusions

30.8.1 At this stage of the design of the Project, it is not possible to carry out a project-specific life cycle greenhouse gas inventory analysis, as detailed specifications of the Project elements are required to complete such an exercise.

30.8.2 Substantial work has, however, been carried out in this area and the results published; some in peer-reviewed scientific journals. The results of such studies can be used to give an indication of the carbon footprint of the Project.

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[3] The calculation is based on a typical wind farm lifecycle carbon emission rate of 15gCO_2e/kWh derived from recent published studies. This has the effect that calculated carbon emissions are proportional to the installed capacity of the wind farm and so a smaller capacity, at say 525MW, will result in proportionately less lifecycle carbon emissions. Both the carbon emissions and the electricity production are lower and hence there is no effect on the time required for the project to achieve carbon neutrality. It is anticipated that as the industry matures, more specific data would become available to estimate more accurately the effect of wind farm size (due to economies of scale and increased efficiency).

[4] Assuming 8 months to attain carbon neutrality, a 700MW project would generate up to 1.51 TWh of 'green' electricity, whereas a 525MW project would generate up 1.13 TWh of 'green' electricity over its lifetime.

30.8.3 The most representative studies find that electricity from offshore wind generation has a lifecycle carbon footprint of between 4 and 13gCO_2e/kWh. This is heavily weighted to the materials manufacture stage and particularly the extraction and processing of iron ore into steel for the turbines, foundations and cabling. Other lifecycle stages such as installation, operation and transport were generally found to be much less significant contributors to the lifecycle footprint. At the end of the turbines' life, they can be recycled or reused and this makes a beneficial contribution to the carbon footprint, as it avoids the need for the extraction and processing of virgin materials for the application they are put to.

30.8.4 This lifecycle electricity footprint can be compared with the current UK grid electricity mix (based substantially on fossil-fuelled generation), which has a footprint of 547gCO_2e/kWh. This is clearly many times higher than the Project's predicted carbon footprint and illustrates the greenhouse gas savings that result from offshore wind electricity generation. Renewable UK, alternatively, use a somewhat lower standard factor to calculate emissions savings. Using either of these factors, and even with conservative assumptions around the Project's footprint and its lifetime, it is concluded that the Project will 'pay back' the carbon emitted in its lifetime in less than a year. After this, it will of course continue to save emissions throughout its lifetime.

30.8.5 Direct offshore emissions of greenhouse gases from the movements of vessels during construction, operation and decommissioning have also been estimated, along with the emissions from the most significant onshore construction activities' vehicles and equipment. The assessment shows that, based on the lifetime generation as discussed in paragraph 30.7.1, the contribution to the Project's lifecycle normalised footprint of the direct onshore emissions from construction, operation and decommissioning of the onshore cable and substation is estimated to be 0.3g/kWh. The contribution of the offshore vessel emissions is estimated to be 3.3g/kWh. These emissions are about a quarter of the total lifetime emissions from the wind farm.

30.8.6 The estimate for onshore direct emissions agrees, in general terms, with the published studies discussed in Section 30.5. They show generally low contributions from onshore construction work, even when that work includes construction of the wind farm itself. The offshore vessel emissions are harder to benchmark, since there are fewer published studies of offshore wind farms. It is clear, however, that the estimate for this Project exceeds that calculated for some other wind farms (e.g. that assessed by Properzi & Herk-Hansen), and hence the estimates presented here can be considered to be conservative.

30.8.7 The total normalised carbon footprint for the Project's electricity of 15 gCO_2e/kWh as used in paragraph 30.7.1 to calculate the carbon payback period accounted for the higher contribution of the vessel emissions calculated in this assessment compared to the published studies, which report a lower normalised footprint.

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