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8A Carbon Balance Review

8A.1 Introduction

8A.1.1 Scope

1 This appendix presents research and calculations relating to the potential energy generated and carbon dioxide (CO_2) emissions savings arising from the Development. The results of the calculations and information provided in this document are presented within the context of electricity consumption within the UK and Scotland, and CO_2 emission savings are reported within the context of Scottish CO_2 emissions.

2 The research and calculations presented within this document are based on an example export capacity of 700 MW (which reflects Inch Cape Offshore Limited's (ICOL's) grid connection offer). Results are generally presented as average annual figures although it is noted that generation output from the Development will vary annually due to wind conditions. Benefits will accrue over the operational life of the Development. It is anticipated that the operational life of the Development will be up to 50 years. Figures are presented in 5-year increments from 25 years to 50 years.

3 The calculations present CO_2 emissions savings from energy generation from the Development. An indicative assessment of CO_2 costs arising from construction, operations and decommissioning of the Development is included.

4 As site-specific data for capacity factor is not currently available, the electricity generated has been calculated using an offshore UK capacity factor derived from the average of the last five years of published figures provided by the Department for Business, Energy and Industrial Strategy (BEIS, 2017), previously, the Department of Energy and Climate Change (DECC).

5 The following information is also presented on the basis of the above scope assumptions:

- The potential equivalent number of Scottish and UK households that could be powered by the wind farm.
- The amount of coal, gas and fossil fuels used to produce the equivalent amount of power generated by the wind farm.
- The potential CO_2 emissions savings of the wind farm over coal-fired, gas-fired and fossil fuel mix electricity generation.

8A.2 Potential Electricity Generation Produced by the Development

6 The potential electricity generation of a wind farm is calculated using the total capacity of the wind farm, the time over which generation occurs and the predicted capacity factor[1].

7 Capacity factors for onshore and offshore wind farms show a good correlation with the UK average wind speed (BEIS, 2017) and therefore, exhibit considerable annual variation. In the absence of a site-specific capacity factor figure for the Development, an average figure for capacity factor, based on published information, is considered to be more representative than a single annual figure. As such, the annual figures for offshore UK wind capacity factors have been obtained from BEIS for years 2012 through to 2016 (BEIS, 2017), as shown in Table 8A.1, from these figures, an average figure of 37.9% was calculated.

Table 8A.1: BEIS published offshore UK capacity factors 2012-2016 and calculated average (%)

2012	2013	2014	2015	2016	Average
35.8	39.1	37.3	41.5	36	37.9

8 The following tables provide the potential electricity generation figures for the Development based on the average capacity factor shown in Table 8A.1.

Table 8A.2: Potential electricity generation produced by the Development - Annual

<table>
<tr><th>Capacity Factor</th><th>Export Capacity (MW)</th></tr>
<tr><td>37.9</td><td>700</td></tr>
<tr><th colspan="2">Potential Electricity Generated (MWh/year)</th></tr>
<tr><td colspan="2">2,324,028</td></tr>
</table>

[1] The potential generation figures presented in the calculations undertaken here are based on a commonly used industry formula which multiplies the total MW capacity of the wind farm by the time over which generation occurs and the capacity factor. Methodology available from Renewable UK, 2018.

Table 8A.3: Potential electricity generation produced by the Development - Lifetime

Operational Life	Potential electricity generated in operational period (GWh)
25 years	58,100
30 years	69,720
35 years	81,341
40 years	92,961
45 years	104,581
50 years	116,201

8A.2.1 Potential Electricity Generation Produced by the Development in the Context of Offshore Renewables

9 In relation to the Development contribution to electricity generated by offshore renewables in general; in 2016 offshore wind generated a total of 16,406 GWh (BEIS, 2017) of electricity in the UK. In the context of this, the potential annual electricity generation produced by the Development (2,324 GWh) would be equivalent to 14% of the 2016 total offshore wind generation in the UK.

8A.2.2 Potential Electricity Generation Produced by the Development in the Context of Scottish and UK Electricity Consumption

10 BEIS produces a range of statistics detailing electricity consumption across the UK. The average domestic electricity consumption in Scotland, was 3, 635 kWh (BEIS, 2018) in 2016, compared to a UK average figure of 3, 781 kWh in 2016. The electricity generated by the Development will enter the National Grid network, and therefore cannot be tracked to the individual consumer, but the electricity will supply demand for the UK and has a grid connection point at Cockenzie in East Lothian.

11 According to the calculated potential generation figures provided in Table 8A.2, the table below provides the equivalent number of household that may be powered per year by the Development.

Table 8A.4: Potential number of households equivalent powered by Inch Cape Offshore Wind Farm

Capacity Factor (%)	Potential Electricity Generated (MWh/year)	**2016 Average Domestic Consumption per household (kWh)** Scotland	**2016 Average Domestic Consumption per household (kWh)** UK	**Potential number of households equivalent powered per year** (based on average Scottish consumption)	**Potential number of households equivalent powered per year** (based on average UK consumption)
37.9	2,324,028	3,635	3,781	639,347	614,660

12 Based on these calculations, the potential electricity generated by the Development will be equivalent to the domestic electricity demand of approximately 640,000 and 615,000 (BEIS, 2018) households based on Scottish and UK domestic consumption respectively, assuming a capacity factor of 37.9% and that the average consumption per household has not changed since 2016.

13 Within Scotland, the number of domestic meter point administration numbers (MPANs) in 2016 was 2,781,000 (BEIS, 2018). The figures for Scotland provided in Table 8A.4 reveal that the proposed development could provide the equivalent of 25% of households in Scotland, assuming the housing level has remained constant.

14 Within the UK, the number of domestic MPANs in 2016 was 28,093,932 (BEIS, 2018). The figures for the UK, provided in Table 8A.4, reveal that the Development could provide the equivalent of 2.2% of households in the UK, assuming the housing level has remained constant.

8A.3 Equivalent Fuel Use

15 Every unit of electricity produced by a wind farm development displaces a unit of electricity which would otherwise have been produced by a conventional (coal or gas) power station and therefore, presents carbon savings. It is the output from coal-fired and gas-fired plant that is adjusted to meet the electricity demand on the system; therefore, wind power replaces the output of these power stations as these are the most flexible plant on the system (wind-generated electricity does not replace electricity from other renewables sources or nuclear power stations). The calculations below use a historical series of published figures from BEIS (formerly DECC) for annual fuel used and electricity generated for 2007 through to 2016 (BEIS, 2017). They also use a conversion factor of 0.085985 which converts alternative units (e.g. GWh) into the common unit of energy for comparing and aggregating fuels, i.e. tonne of oil equivalent (toe).

8A.3.1 Coal

16 Based on the BEIS figures (BEIS, 2017) for fuel use 2007-2016, the average amount of coal used to produce a GWh of electricity is 240 toe [i.e. 0.240 thousand toe (ttoe)][2]. Using this average figure and the potential annual generation figure for the Development shown in Table 8A.4, it can be calculated that the Development has the potential to replace approximately 557,766 toe (557.77 ttoe) of coal. To place this into context, in 2016, 7,040 ttoe of coal was used to produce 31,000 GWh of electricity for the UK; the Development, therefore, has the potential to replace the equivalent of approximately 8% of this annual coal usage in 2016.

8A.3.2 Gas

17 The historical series of published figures from BEIS for 2007-2016 also report on gas used for electricity generation. Using these figures, the average amount of gas used to produce a GWh of electricity is 184 toe [i.e. 0.184 ttoe]. Using this average figure and the potential annual generation figure from the Development shown in Table 8A.4, it can be calculated that the Development has the potential to replace the equivalent of approximately 427,621 toe (427.62 ttoe) of gas. Again, to place this into context, in 2016, 25,000 ttoe of gas was used to produce 143,000 GWh of electricity; therefore, the Development has the potential to replace the equivalent of approximately 1.7% of this annual gas usage.

8A.4 Potential CO_2 Emission Savings Produced by the Development

8A.4.1 CO_2 Savings

18 The amount of CO_2 emissions produced during energy production varies with the type of fuel used; therefore, the potential CO_2 savings from the Development depends on the type of fuel it replaces.

19 The wind farm CO_2 emissions savings over other types of generation (i.e. coal-fired, gas-fired, fossil-fuel mix) is calculated by multiplying the energy output of the Wind Farm by the emissions factor of the other type of generation.

20 CO_2 emissions from power stations vary by type of fuel used. In addition, the emissions for different types of electricity generation show annual variations. DECC publishes the annual estimated emissions (tCO_2/GWh) from electricity generation for different fuel types in their annual Digest of UK Energy Statistics (BEIS, 2017). Although the annual variations are fairly small, the average CO_2 emissions for gas, coal and the fossil fuel mix for years 2014-2016, sourced from the 2017 Digest, have been calculated. These average emissions figures (0.911 tCO_2/MWh, 0.376 tCO_2/MWh and 0.584 tCO_2/MWh for coal, gas and all fossil fuels respectively) are known as the emissions factor for that fuel type and are used in the following calculations.

[2] The calculation for this figure was based on dividing the annual amount of fuel used in ttoe (using the conversion factor to convert from GWh to ttoe) by the total annual electricity generation (GWh) of that fuel.

21 Using the above emissions factors and the potential generation produced by the Development shown in Table 8A.4, the potential CO_2 emissions savings from the Development electricity generation are calculated and shown in Table 8A.5 over a range of operational periods.

Table 8A.5: Potential CO_2 emissions savings produced from the Development

Potential Electricity Generated (MWh/year)	Potential annual CO_2 emissions savings over coal-fired generation (tCO_2/year)	Potential annual CO_2 emissions savings over gas-fired generation (tCO_2/year)	Potential annual CO_2 emissions savings over fossil fuel mix generation (tCO_2/year)
2,324,028	2,117,189	873,834	1,357,232
Operational Life	**Potential CO_2 emissions savings from electricity generation over coal-fired generation ($MtCO_2$)**	**Potential CO_2 emissions savings from electricity generation over gas-fired generation ($MtCO_2$)**	**Potential CO_2 emissions savings from electricity generation over fossil fuel mix generation ($MtCO_2$)**
25 years	52.92	21.85	33.93
30 years	63.52	26.22	33.93
35 years	74.10	30.58	47.50
40 years	84.69	34.95	54.29
45 years	95.27	39.32	61.10
50 years	105.86	43.69	67.86

22 Using the BEIS average capacity factor (37.9% for the inclusive period of 2012 to 2017), the Development has the potential to produce CO_2 emissions savings of 2,117,189 tCO_2 per year (i.e. 2.11 million tCO_2 [$MtCO_2$]), 873,834 tCO_2 per year (i.e. 0.87 MtCO2) and 1,357,232 tCO_2 (1.36 Mt CO_2) per year over coal-fired, gas-fired and fossil fuel mix electricity generation respectively.

8A.4.2 CO_2 Costs

23 CO_2 emissions will arise from the manufacture of Wind Turbine Generators (WTGs) and other components, and from construction, operations and decommissioning of the Development. At this stage of the Development, many of the specific elements that will result in emissions are not yet defined. These include WTG make and model, substructure and foundation type and therefore material selection, and installation methods which will affect vessel selection. Operations and maintenance requirements and support locations are also not yet defined. It is only possible at this stage to provide an indicative assessment of CO_2 emissions that will arise from construction, operations and decommissioning of the

Development based on published data. A 2010 climate declaration (EPD, 2013) in relation to Vattenfall's Nordic Wind Farms (including Horns Rev and Lillgrund) provides verified results from a life cycle assessment (LCA) performed as basis for an EPD (Environmental Product Declaration), in accordance with ISO 14025 (Vattenfall, 2010). The declaration shows the emissions of greenhouse gases, expressed as CO_2-equivalents as shown in Table 8A.6.

Table 8A.6: Emissions of greenhouse gases, expressed as CO_2-equivalents

	Grams CO_2 equivalent per KWh
Oils used in plant	0.23
Operations	0.16
Construction, reinvestments and decommissioning	13.56
Total	**13.95**

24 CO_2 costs for the Development have been estimated on this basis. Table 8A.7 below summarises the savings, costs and net savings of CO_2 over a range of operational periods based on savings from a fossil fuel mix as per Table 8A.6.

Table 8A.7: Potential CO_2 emissions savings produced from the Development

Operational Life	**Potential CO_2 emissions savings from electricity generation over fossil fuel mix generation ($MtCO_2$)**	**Potential CO_2 costs from Development ($MtCO_2$)**	**Net CO_2 emissions savings from Development based on fossil fuel mix ($MtCO_2$)**
25 years	33.93	0.81	33.12
30 years	40.72	0.97	39.75
35 years	47.50	1.13	46.37
40 years	54.29	1.30	52.99
45 years	61.10	1.46	59.64
50 years	67.86	1.62	66.24

25 Based on this scenario, the time taken to payback the CO_2 costs of the Development through offsetting emissions from a fossil fuel mixed generation would be approximately 14 months[3].

8A.4.3 Backup Generation

26 Wind generated electricity is inherently variable and may require backup power from other forms of generation in order to manage the supply to the consumer. The extra capacity needed for backup power generation is estimated at 5 % of the rated wind farm capacity if all the wind power schemes within the UK contribute more than 20 % of the total supply to the National Grid (Dale *et al.* 2004 cited in Nayak *et al.* 2010). If fossil fuel provides the backup, there will be carbon emissions associated with this back up.

27 It is likely that the contribution from UK wind energy sources will increase to more than 20% of the total supply of the National Grid during the assumed lifetime of the Development. As such, backup power generation may be required at some point in the future depending on how and when this Development and other projects progress to construction and operation. The emissions associated with backup have not been taken into consideration within the calculations made above.

8A.4.4 Potential CO_2 Emissions Savings Produced by the Development in the Context of Scottish Emissions

28 To place the above CO_2 emissions savings calculations into context, the potential CO_2 emissions savings produced by the Development and presented in Table 8A.7 can be compared to the latest published figures for CO_2 emissions at a Scottish national level. These published estimates reveal that the total CO_2 emissions estimate for Scotland in 2014 was 46.7 $MtCO_2$ (Scottish Government, 2016).

29 As such, based on the annual generation figures using the average BEIS capacity factor, the expected annual CO_2 emission savings from the Development could account for the equivalent of between approximately 1.8% (over gas-fired generation), 2.9% (over fossil fuel mix generation) to 4.5% (over coal-fired generation) of the total CO_2 emissions estimate for Scotland in 2014, assuming that gas-fired, coal-fired and fossil fuel mix generation are replaced alone.

30 Furthermore, as the Scotland figure of 46.7 $MtCO_2$ includes transport, industrial and commercial, as well as agricultural CO_2 emissions; when examining the CO_2 emissions estimates for domestic electricity usage for Scotland in 2015 (9.865 $MtCO_2$[4]), the expected

[3] Based on the Development offsetting 1, 357, 232 tCO_2/year over fossil fuel missed generation and the Development cost being 1.6 $MtCO_2$ over the 50 year lifetime. Calculated as follows: 1,357,232/12 months = 113,102.667 tCO_2/month over fossil fuel missed generation. 1.62 $MtCO_2$/113,102.667 tCO_2/month = 14.3 months.

[4] The emissions associated with domestic electricity consumption have been estimated using an average UK factor for the relevant year in terms of kt CO_2 per GWh. This average allocates equal shares of coal, gas, oil and renewable powered generation to all the domestic electricity consumers and is derived from the UK inventory for 2015. Available online from: https://www.gov.uk/government/collections/uk-local-authority-and-regional-carbon-dioxide-emissions-national-statistics (last accessed 22/03/2018)

annual CO_2 emission savings from the Development could account for the equivalent of between approximately 8.8% (over gas-fired generation), 13% (over fossil fuel mix generation) to 21.2% (over coal-fired generation) of the total CO_2 emissions estimate for Scotland in 2015, assuming that gas-fired, coal-fired or fossil fuel mix generation are replaced alone.

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