Shetland Strategic Wider Works

Levelised Cost of Energy (LCOE) Analysis

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GB Economic Assessment, Network Development,
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Faraday House
Gallows Hill
Warwick
CV34 6DA
www.nationalgrideso.com

1. Summary

An analysis of Levelised Cost of Energy has been carried out to compare the LCOEs for the Shetland onshore windfarm and an equivalent offshore windfarm option. The analysis was undertaken with the latest BEIS LCOE model and using BEIS input data, which was supplemented with Shetland generation output data from NGESO's pan European market model (BID3). This BID3 data was used for both the Shetland SWW Needs Case Cost Benefit Analysis and the onshore wind options within the LCOE analysis. This ensured consistency and enabled a detailed comparison of the various onshore options to the offshore wind options.

The analysis shows that when net HVDC capital costs are included within the onshore windfarm options, the 600 and 800MW HVDC link options, combined with the 638, 705 or 810MW generation capacity, produce lower LCOEs than the equivalent offshore windfarm.

2. Introduction

This note provides a high-level overview of the methodology for the Levelised Cost of Energy (LCOE) analysis to be undertaken for Shetland Strategic Wider Works.

LCOE is the discounted lifetime cost of ownership and use of a generation asset, converted into an equivalent unit of cost of generation in £/MWh. The LCOE of a particular generation technology is the ratio of the total asset costs of a plant (including both capital and operating costs), to the total amount of electricity expected to be generated over the plant's lifetime. Both are expressed in net present value terms (NPV), hence the future costs and outputs are discounted when compared to costs and outputs today.

3. Methodology

LCOE can be expressed by the following equations:

$$\text{LCOE} = \frac{\text{NPV of Total Costs}}{\text{NPV of Electricity Generation}}$$

$$\text{LCOE} = \frac{\sum_{t=1}^{t} (\text{Annual capex} + \text{fixed} + \text{variable cost})/(1+r)^{t}}{\sum_{t=1}^{t} (\text{Annual electricity generation})/(1+r)^{t}}$$

Where:

Fixed costs includes operational and maintenance costs
Variable costs includes fuel and carbon costs
t = technology lifetime
r = hurdle rate, i.e. the minimum project return that a plant owner would require over a project's lifetime

The following high-level methodology has been applied:

1. Use BEIS LCOE model
2. Calibrate the revised model by using BEIS input data for onshore and offshore windfarms and checking model outputs agree with BEIS results

3. Modify model to incorporate plant load factors from BID3 modelling and HVDC link data from NGESO Shetland SWW Needs Case: CBA

The generation output assumptions used within the NGESO Shetland SWW Needs Case: CBA were used within the LCOE onshore wind analysis to ensure that the onshore wind modelling represented the Shetland options as closely as possible.

4. Assumptions

CAPEX

Wind generation costs

Wind generation CAPEX costs were obtained from BEIS. Offshore Wind construction costs figures are shown in Table 1 below and Onshore Wind construction costs are shown in Table 2 below for Earliest in Service dates of 2024 and 2026.

Table 1: Offshore wind construction costs

Offshore Wind construction cost, Round 3 (£/kW)	BEIS, Feb 2020 (2018 real values), operation start 2024	BEIS, Feb 2020 (2018 real values), operation start 2026
High	redacted	redacted
Medium	redacted	redacted
Low	redacted	redacted

Table 2: Onshore wind construction costs

Onshore Wind construction cost, (£/kW)	BEIS, Feb 2020 (2018 real values), operation start 2024	BEIS, Feb 2020 (2018 real values), operation start 2026
High	redacted	redacted
Medium	redacted	redacted
Low	redacted	redacted

Infrastructure costs

The costs for the HVDC link for onshore wind were used from the NGESO CBA, converted to 2018 prices. These are shown in Table 3.

Table 3: HVDC link costs

HVDC link cost, 2018 prices (£m)	EISD 2024	EISD 2026
450MW	redacted	redacted
600MW	redacted	redacted
800MW	redacted	redacted

These are netted off against the latest estimates of the cost of a DNO connection, i.e. the cost of building a DNO link to support demand on Shetland if the HVDC link does not get built. The net HVDC link costs are shown in Table 4.

Table 4: HVDC link costs net of DNO costs

Net HVDC link cost, 2018 prices (£m)	EISD 2024	EISD 2026
450MW	redacted	redacted
600MW	redacted	redacted
800MW	redacted	redacted

For the offshore windfarms, Offshore transmission (‘OFTO’) construction costs for the electricity transmission cable are excluded from the analysis: OFTO payments are assumed to be made by the wind farm owner and paid to the owner of the transmission cable and captured via operating costs.

Operating and Maintenance (O&M) costs

O&M costs for onshore and offshore windfarms were provided by BEIS.

Asset Life

Asset life assumptions were taken from BEIS data. Onshore windfarms were assumed to have an operating life of 25 years and offshore windfarms were assumed to have an operating life of 30 years.

Generation load factor

For onshore windfarm LCOE calculations, the load factor outputs from BID3 have been used. These load factors are the generation output data from our BID3 modelling undertaken for the NGESO Shetland SWW Needs Case: CBA report. These load factors vary across different levels of generation capacity and HVDC link capacity. For offshore windfarms BEIS annual load factor assumptions have been used.

Table 5: Onshore and offshore average wind load factors over lifetime of asset (Earliest in Service Date 2024)

Onshore wind		
HVDC link size	Generation capacity	Average load factor over 25 years
Op 1 (450MW)	S1 (458MW)	redacted
Op 1 (450MW)	S2 (638MW)	redacted
Op 1 (450MW)	S3 (705MW)	redacted
Op 1 (450MW)	S4 (810MW)	redacted
Op 2 (600MW)	S1 (458MW)	redacted
Op 2 (600MW)	S2 (638MW)	redacted
Op 2 (600MW)	S3 (705MW)	redacted
Op 2 (600MW)	S4 (810MW)	redacted
Op 3 (800MW)	S1 (458MW)	redacted
Op 3 (800MW)	S2 (638MW)	redacted
Op 3 (800MW)	S3 (705MW)	redacted
Op 3 (800MW)	S4 (810MW)	redacted
Offshore wind		
Earliest in Service Date (EISD)		Average load factor over 30 years
2024		redacted
2026		redacted

Hurdle (Discount) Rates

The hurdle rate is the minimum rate that a company expects to earn when investing in a project. The hurdle rate is the company's required rate of return. Hurdle rates supplied by BEIS have been used within this analysis.

Table 6: Hurdle rates

	Onshore wind	Offshore wind
Hurdle rate	redacted	redacted

Discounting

For discounting purposes, the base year is set to 2018, with prices in 2018 values.

5. Sensitivities

Levelised cost estimates are highly sensitive to underlying data and assumptions, for example capital costs, operating costs, load factors and hurdle rates. The following sensitivities were considered.

- High, medium and low construction costs as supplied by BEIS were used.
- Variations in hurdle rates were tested by:
  - rerunning the onshore cases with a hurdle rate equal to that used for offshore wind: **redacted**, and
  - rerunning the offshore cases with a hurdle rate equal to that used for onshore wind: **redacted**,
- A tipping point analysis was undertaken to understand how much onshore windfarm construction cost would have to increase by for the onshore windfarm LCOE to be higher than the equivalent offshore windfarm case

6. Model Calibration

To ensure that the NGESO LCOE model was working correctly, the outputs from the NGESO LCOE model using BEIS input data was compared to results received from BEIS. The model produced very good agreement for both onshore and offshore windfarm results.

Table 7: Test case LCOE results from NGESO model and BEIS

Test Case	Onshore or Offshore?	EISD	Construction cost (£/kW)	Discount rate	Gen. cap. (MW)	Operating life (years)	LCOE (£/MWh) BEIS	LCOE (£/MWh) NGESO	% diff. in LCOE
A	Onshore	2024	redacted	redacted	red.	25	red.	redacted	red.
B	Offshore	2025	redacted	redacted	red.	30	red.	redacted	red.
C	Offshore	2040	redacted	redacted	red.	30	red.	redacted	red.

Table 4 shows that the percentage difference between LCOE results from the two models varies between **redacted** and **redacted**.

7. Results

For ease of comparison, Figure 1 shows the results for a small subset of the cases, all of which use BEIS medium pre-development and construction costs and have an earliest in-service date of 2024. The onshore windfarm options all have Option 1, the 450MW HVDC link. It shows the results for cases:

1. Offshore Med con 24 – Offshore windfarm, Medium construction costs, EISD of 2024
2. Option1 S1 Med con 24 no HVDC – Onshore windfarm, HVDC Option1 (450MW), S1 generation background (459MW) Medium construction costs, EISD of 2024, no HVDC costs included
3. Option1 S1 Med con 24 – Onshore windfarm, HVDC Option1 (450MW), S1 generation background (458MW), Medium construction costs, EISD of 2024

4. Option1 S2 Med con 24 – Onshore windfarm, HVDC Option1 (450MW), S2 generation background (638MW), Medium construction costs, EISD of 2024
5. Option1 S3 Med con 24 – Onshore windfarm, HVDC Option1 (450MW), S3 generation background (705MW), Medium construction costs, EISD of 2024
6. Option1 S4 Med con 24 – Onshore windfarm, HVDC Option1 (450MW), S2 generation background (810MW), Medium construction costs, EISD of 2024

Figure 1: LCOE for medium construction costs, EISD 2024 and onshore windfarm HVDC link Option1 (450MW)

redacted

Figure 1 shows the LCOE broken down into five constituent parts:

- **Pre-development** – pre-development costs for the windfarm
- **Construction** – includes windfarm capital costs and infrastructure costs
- **Fixed O&M** – fixed operation and maintenance costs, including insurance, Connection and Use of System costs
- **Variable O&M** – variable operation and maintenance
- **Decommissioning** – decommissioning costs

Figure 1 shows several key points that apply to all of the results:

- The first bar shows the higher Fixed O&M costs for offshore windfarms, compared to the onshore windfarms.
- The second bar shows that when the costs of the HVDC costs are not included for onshore windfarms, the LCOE is considerably lower than for a broadly equivalent offshore windfarm option (**redacted** £/MWh compared to **redacted** £/MWh)
- The third, fourth, fifth and sixth bars show the LCOE for the smallest HVDC link and the four Shetland generation backgrounds
    - There is relatively little difference between the four total LCOE results (**redacted** £/MWh to **redacted** £/MWh)
    - The construction cost element of the LCOE is roughly doubled when the HVDC link costs (specifically the HVDC cost net of DNO costs) are included (**redacted** £/MWh compered to **redacted** £/MWh in the second bar)

Figure 2 shows the equivalent results but the onshore windfarm options all have Option 3, the 800MW HVDC link. Figure 2 does not show an onshore windfarm option that excludes net HVDC costs.

Figure 2: LCOE for medium construction costs, EISD 2024 and onshore windfarm HVDC link Option3 (800MW) for the four generation backgrounds (S1 to S4) and equivalent offshore windfarm case

redacted

Figure 2 shows that the largest HVDC link (Option 3: 800MW) results in LCOEs for the three largest Shetland onshore windfarm generation backgrounds that are lower than for the equivalent offshore windfarm option. The LCOEs for the onshore windfarm options are significantly lower than in Figure 1, due to the increased levels of generation with the larger sized link, particularly with the larger generation backgrounds (**redacted** £/MWh for Option 3 compared to **redacted** for Option 1).

Figure 3, 4 and 5 show a broader dataset: for onshore windfarms, the four Shetland generation backgrounds, for each HVDC link option size (Options 1 to 3), for high, medium and low construction costs (ie 36 cases). For offshore windfarms, the equivalent high, medium and low construction cost cases are shown.

Figure 3: LCOE for high construction costs for onshore and offshore windfarm cases with an EISD of 2024

redacted

Figure 4: LCOE for medium construction costs for onshore and offshore windfarm cases with an EISD of 2024

redacted

Figure 5: LCOE for low construction costs for onshore and offshore windfarm cases with an EISD of 2024

redacted

Figures 3,4 and 5 all show similar results:

- Option 1, the 450MW link shows an increase in LCOE as the generation capacity on Shetland increases (left to right on the charts), because of the increase in construction costs and generation output volumes are constrained, i.e. the additional generation is limited by the size of the HVDC link.
- Option 3, the 800MW link shows a decrease in LCOE as the generation capacity on Shetland increases, because the increase in construction costs for the larger HVDC link and larger generation is more than offset by the increasing levels of generation output that is not constrained with the larger sized link.
- All onshore windfarm LCOEs are lower than the equivalent offshore windfarm LCOE, apart from the Option 3, S1 case, that is the largest sized HVDC link (800MW), and the smallest generation capacity on Shetland (450MW): the higher HVDC link costs are not offset by the relatively low levels of generation on Shetland.
- The onshore windfarm option with the largest HVDC link (Option 3: 800MW) and largest Shetland generation capacity (S4: 810 MW) show the lowest LCOE for the high, medium and low construction cost cases.

Figures 6, 7 and 8 show the equivalent results but for an EISD of 2026 for both onshore and offshore windfarms.

Figure 6: LCOE for high construction costs for onshore and offshore windfarm cases with an EISD of 2026

redacted

Figure 7: LCOE for medium construction costs for onshore and offshore windfarm cases with an EISD of 2026

redacted

Figure 8: LCOE for low construction costs for onshore and offshore windfarm cases with an EISD of 2026

redacted

The most striking difference between figures 3, 4 and 5 and figures 6, 7 and 8, i.e. the EISD of 2024 and 2026 are the significantly lower LCOEs for offshore windfarms with an EISD of 2026. This is driven by two major assumptions. The first is the greater reduction in construction costs in offshore windfarms from 2024 to 2026 compared the cost reductions in onshore windfarms (for example, for medium construction cost assumptions, there is a **redacted** cost reduction in offshore windfarms from 2024 to 2026, but only a **redacted** reduction over the same period for onshore windfarms). The second is the increase in average annual load-factor for offshore windfarms from 2024 to 2026 (**redacted** to **redacted**).

Sensitivity: Onshore Wind hurdle rate set to **redacted**

Figure 9: LCOE for medium construction costs for onshore and offshore windfarm cases with an EISD of 2024 and a hurdle rate of redacted for both onshore and offshore windfarms

redacted

Figure 9 shows that with the higher hurdle rate of **redacted**, fewer onshore windfarm cases are lower than the offshore LCOE compared to Figure 4.

Sensitivity: Offshore Wind hurdle rate set to **redacted**

Figure 10: LCOE for medium construction costs for onshore and offshore windfarm cases with an EISD of 2024 and a hurdle rate of redacted for both onshore and offshore windfarms

Like Figure 9, Figure 10 also shows with the lower hurdle rate of **redacted** for offshore windfarms, fewer onshore windfarm cases are lower than the offshore LCOE compared to Figure 4.

Tipping point analysis

An investigation was undertaken to quantify how much construction costs would need to increase for onshore wind to have a higher LCOE than offshore wind. The results are shown in Table 8.

Table 8: Tipping point analysis: Medium construction costs

	Option 2 (600MW) S4 (810MW) EISD 2024 Medium construction costs	Option 2 (600MW) S4 (810MW) EISD 2024 With revised construction costs	Offshore EISD 2024
Construction cost (£/kW)	redacted	redacted	redacted
LCOE (£/MWh)	redacted	redacted	redacted

Table 8 shows that for onshore windfarm Option 2 S4 medium construction costs, construction costs would have to increase by **redacted** (from **redacted** £/kW to **redacted** £/kW) for the LCOE to be greater than the equivalent Offshore windfarm case (i.e **redacted** £/MWh is greater than **redacted** £/MWh). **redacted** £/kW is significantly higher than the high construction cost assumption of **redacted** £/kW.

8. Conclusions

- The Impact of including the net cost of the HVDC is significant on the LCOE for onshore windfarms.
- For the 600 and 800MW HVDC links, for both the 2024 and 2026 EISD cases, the 638, 705 and 810MW generation background cases all result in LCOEs that are lower than the equivalent offshore windfarm cases.
- The onshore windfarm cases with the largest HVDC link and the largest Shetland generation (i.e. Option 3: 800MW, S4: 810MW) produce the lowest LCOEs, for both the 2024 and 2026 EISD cases.