COMMERCIAL COST-BENEFIT ANALYSIS OF DOGGER BANK WINDFARM

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1. Overview

Transition from an energy mix dominated by fossil-fuel based energy generation to an energy mix with larger proportions of renewable energy, is on the agenda for many countries. The motivation is related to combatting climate change issues and to assure energy supply security. Renewable energy is capital intensive. If we are to reach the climate change goals within stated timeframes, investments from private companies are arguably a necessity. In particular, oil and gas companies have capital and competence needed to undertake large, renewable energy project. The decision-making of private companies, however, are not primarily driven by economics arguments but rather by financial arguments. In other words, the projects must be profitable from the companies' perspective when using financial criteria such as net present value, internal rate of return and payback period (Osmundsen et al., 2021). Interestingly, as argued by Jaraite and Kazukauskas (2013) and Aguirre and Ibikunle (2014), there is a gap in the literature pertaining the business economics of renewable energy projects. We aim to fill some of this gap by demonstrating how a cost-benefit analysis can be undertaken, and we discuss the key input parameters. The principal cost-benefit approach is illustrated by the Dogger Bank Windfarm.

Dogger Bank Windfarm is scheduled to be the largest offshore wind farm in the world by the time of its completion. The development site is located more than 130 km to the east of the coast of Yorkshire in the UK part of the North Sea. The water depth ranges from 20 to 35 metres. Dogger Bank consists of three projects: DBA, DBB and DBC. It was initially planned to have 100 12MW wind turbine generator of the Haliade-X series. The wind farm will have a capacity of 3.6GW, enough to provide 4.5 million British homes with electricity. This corresponds to roughly 5% of the energy consumption in UK. The projects are a joint venture between Equinor, SSE Renewable and ENI. Cost estimates suggest an investment cost of GBP 9 billion, which is to be invested between 2020 and 2026. The lifespan of Dogger Bank Windfarm is expected to be 25 years.

2. Methods

There are two key objectives of our paper. First, we aim to develop a baseline scenario where we estimate the expected net present value (NPV) of the Dogger Bank Windfarm projects. Second, we discuss the uncertainty of the baseline estimate. With our analysis, we elucidate which factors, constituting the NPV calculation, are the most uncertain and have the greatest impact. Given a set of inputs, the net present value is straightforward to calculate. See Equation (1).

$$\begin{matrix}Net\\Present\\Value\end{matrix} = \sum_{t=1}^{T} \frac{\begin{matrix}Cash\\Flow_t\end{matrix}}{\left(1+\begin{matrix}Discount\\rate\end{matrix}\right)^t} - \begin{matrix}Investment\\cost\end{matrix} \tag{1}$$

However, considerably more effort is required to estimate the various inputs. Based on information from Equinor's press release, we know the estimated capex. With empirical analysis of past projects (Dahl et. Al., 2017; Lorentzen et. Al., 2017, Sovacool, 2017), a probability density function can be inferred for cost overruns.

Calculating net present value, given a set of input variables, is a straightforward task. The challenge lies in estimating the input variables. The Project Management Institute's (PMI) Project Management Body of Knowledge (PMBOK), gives insight into the established best-practice of the project management industry when it comes to estimating these input variables. In accordance with best-practice, higher level of estimation accuracy can be achieved by utilizing the bottom-up approach. This involves developing a breakdown structure and then estimate each work package. Each work package is either a known variable or estimated using a combination of expert judgment and parametric estimation techniques. The core idea behind a breakdown structure is to partition a variable of unknown value into chunks whose values are either known or unknown. Not only does this elucidate the limitations of our calculations, but it is likely to increases the overall estimation accuracy.

The discount rate calculated with the weighted average cost of capital (WACC) equation. See Equation (2).

$$WACC = \frac{Debt}{Debt + Equity} \cdot \begin{matrix}Cost\ of\\Debt\end{matrix} \cdot \left(1 - \begin{matrix}corporate\\tax\ rate\end{matrix}\right) + \frac{Equity}{Debt + Equity} \cdot \begin{matrix}Cost\ of\\Equity\end{matrix} \tag{2}$$

Further estimation is required to establish the cost of equity. In our case, we apply the capital asset pricing model. See Equation (3).

$$\begin{matrix}\mathit{Cost\ of} \\ \mathit{Equity}\end{matrix} = \begin{matrix}\mathit{risk\ free} \\ \mathit{interest\ rate}\end{matrix} + \beta \begin{pmatrix}\begin{matrix}\mathit{return\ on} \\ \mathit{market} \\ \mathit{portfolio}\end{matrix} - \begin{matrix}\mathit{risk\ fee} \\ \mathit{interest\ rate}\end{matrix}\end{pmatrix} \tag{3}$$

The most challenging input to estimate is the cash flows throughout the 25 years of expected lifespan. The annual cash flow, throughout operations, is the difference between income and operational expenditure (Opex). The latter is calculated based on parametric cost estimation using empirical data from past wind farm projects. Specifically, lifetime Opex is typically found to be equal to around 90% of nominal Capex or 25-35% of Levelized Cost of Energy (LCoE). A similar approach can be used for the decommissioning cost. The annual income is given as specified in Equation (4).

$$\mathit{Income} = \left(\mathit{Capacity} \cdot (24\ \mathit{hours} \cdot 365\ \mathit{days}) \cdot \begin{matrix}\mathit{capacity} \\ \mathit{factor}\end{matrix} \cdot \mathit{price}\right) \tag{4}$$

Capacity and number of hours in a year, are well-known quantities. A best-case capacity factor is provided by GE, the producers of the Haliade-X wind turbine generators. The capacity factor is defined as the ratio between actual production and the theoretical maximum production. In a future paper we will conduct an extensive literature review and conduct various subject-matter expert interviews to establish a more realistic capacity factor. For the initial 15 years of operation, the windfarm will be subject to a fixed price, which is specified in the contract for difference (CfD). For the final decade of operation, the wind farm will be operating under market prices. Arguably, the market price is the most uncertain input factor to the analysis. Any estimate would come with a high degree of uncertainty. Again, in a future paper we will rely on an extensive literature review and consultation with experts from both the academic and industry domain.

3. The cost-benefit approach

3.1 Capital expenditure

According to Equinor's press release[1], "The Dogger Bank projects are estimated to trigger a total capital investment of approximately GBP 9 billion between 2020 and 2026." Based on the analogous estimation[2] approach, as each of the projects will result in a capacity of 1.2 GW, it is reasonable to assume that the capital expenditure will be divided equally among the three projects. That is, by assumption, each of the projects have an estimated capex of GBP 3 billion. Dogger Bank A and B are, reportedly, quite similar. Dogger Bank C, on the other hand, is more distantly located. Consequently, assuming an equal capex for Dogger Bank A and B is arguably quite reasonable. Whether Dogger Bank C will be equal to A and B is a more tenuous assumption. However, as reported in OffshoreWIND, the estimated cost of Dogger Bank A and B is GBP 6 billion[3], meaning that Dogger Bank C is estimated to entail a capex of GBP 3 billion.

Having established the division of the capital investment among the three projects, we move on to address the timing of the capex. According to Equinor's press release, Dogger Bank A is expected to be operational in 2023. In other words, the investment for Dogger Bank A is scheduled to occur between 2020 and 2023. In the absence of further information, we assume uniformity in the timing of the capex. That is, we assume an annual capex of GBP 1 billion in 2020, 2021 and 2022 for Dogger Bank A. Based on an interview with SSE[4], OffshoreWIND reports that, "Dogger Bank A and B are being constructed at the same time to take advantage of the synergies resulting from their geographical proximity and use of common technology and contractors […]". However, no statement has been made regarding when Dogger Bank B will begin its operation. Hence, we assume that Dogger Bank will follow a similar pattern as Dogger Bank A, but with a one-year delay. More explicitly, we assume an annual capex of GBP 1 billion in 2021, 2022 and 2023 for Dogger Bank B. According to OffshoreWIND[5], Dogger Bank C will have its financial close at the end of 2021 and the wind farm will be fully operational in 2026. Based on this information, we assume an annual investment of GBP 600 million for Dogger Bank C will occur in 2022, 2023, 2024, 2025 and 2026. The

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[1] https://www.equinor.com/en/news/2019-09-19-doggerbank.html 11.01.2021

[2] PMBOK

[3] https://www.offshorewind.biz/2020/11/26/dogger-bank-owners-close-largest-ever-offshore-wind-project-financing/ 11.01.2021

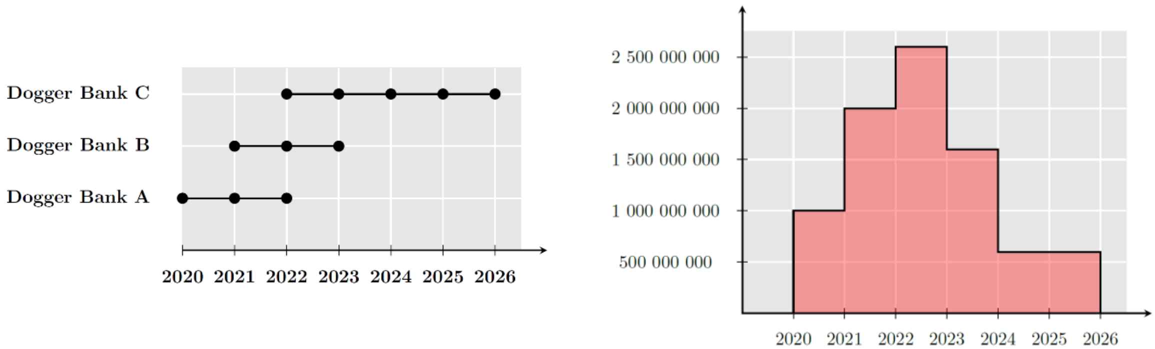
[4] https://www.offshorewind.biz/2020/11/26/dogger-bank-owners-close-largest-ever-offshore-wind-project-financing/ 11.01.2021

[5] https://www.offshorewind.biz/2020/11/26/dogger-bank-owners-close-largest-ever-offshore-wind-project-financing/ 11.01.2021

assumed timeline for the execution phase of the three projects are shown in Figure 1 (a) and the annual capex aggregated across the three projects is shown in subfigure (b).

Figure 1: Execution phase timeline and capex

(a) **Timeline** (b) **Annual capex**



Subfigure (a) shows the assumed duration of the execution phase of Dogger Bank A, B and C. Subfigure (b) shows the annual, aggregate capex across the three projects.

Regarding the estimated capital expenditure of GBP 9 billion, there are two input variables decided by the authors which affect the net present value. The duration of the projects and the shape of the cumulative consumption of resources with respect to time. Let us discuss both of these in further details, beginning with the latter.

We have assumed a linear cumulative consumption of resources throughout the execution phase of the three projects. In other words, we assume that each project's capex occur is spread equally across the duration of the execution phase. This is not a benign assumption as the timing of the investment cost does affect the net present value. Let the present value (PV) of a cash flow (CF) received at time period t with a discount rate of r be denoted as $PV(CF, t, r)$. The effect on present value by delaying or advancing a given cash flow by one time period would be

$$PV(CF, t+1, r) - PV(CF, t, r) = \left(\frac{1}{1+r} - 1\right) \cdot PV(CF, t+1, r) \tag{5}$$

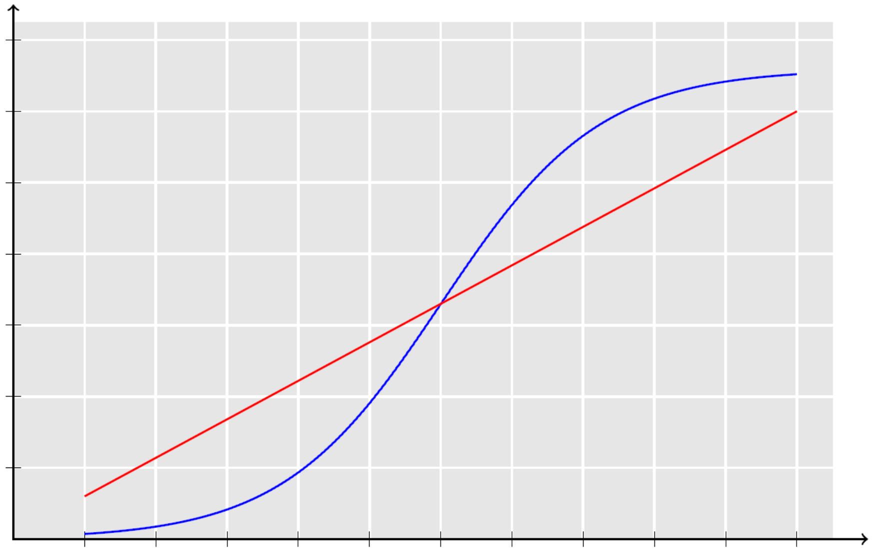
and

$$PV(CF, t-1, r) - PV(CF, t, r) = r \cdot PV(CF, t+1, r), \tag{6}$$

respectively. In other words, by delaying a negative cash flow by one time period, its present value is increased by a growth rate of $1/(1+r) - 1$. Analogously, a negative cash flow that is advanced by one time period will have its present value decreased by a growth factor of r.

It is well known in the project management literature that cumulative consumption of resources typically follows an S-curve. For instance, according to Gardiner (2005, 30), "Consumption of resources begins low during initiation, gains pace during planning, is at full throttle during implementation and tails off rapidly at closure." However, there is an infinite number of possible S-curves we could construct. If we wish to apply an S-curve, in the absence of further information, the default choice would arguably be a symmetric curve. See Figure 2 for a comparison between a linear and s-shaped cumulative consumption of resources. By assuming a linear cumulative curve, part of the capex will occur too soon (decreases NPV) and another part too late (increases NPV). The incorrect timing from a uniform distribution will partly cancel each other out. However, a uniform distribution would not be equivalent with a symmetric S-curve as the growth factor for advancing is greater than the growth factor for delaying, $r > 1/(1+r) - 1$. The effect is, arguably, neglectable.

Figure 2: Linear and symmetric S-shaped cumulative consumption of resources

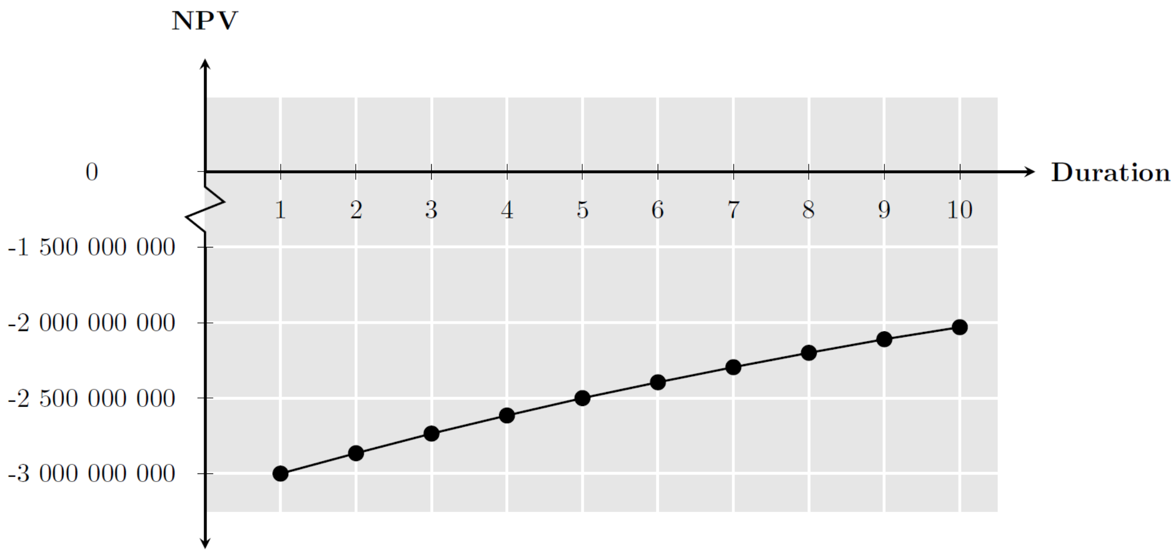


Comparison between linear and symmetric S-shaped cumulative expenditure

Consider the three-year investment period of Dogger Bank A with its GBP 3 billion investment cost. Assuming equal division of capex, i.e. GBP 1 billion per year, results in a net present value of GBP -2 735 537 190 when using an arbitrary discount rate of 10 %. On the other hand, applying the most exaggerated S-curve possible, with GBP 0 in the first and last time period and GBP 3 billion the middle time period, results in a net present value of GBP 2 727 272 727. The difference between these two schedules is GBP 8 264 463 or 0.30 %, which is insignificant in this context.

As it turns out, the assumption of a capex equally divided across each year of the execution phase has a modest effect on the net present value compared to a typical symmetric, S-shaped cumulative consumption of resources. On the contrary, the assumption regarding the duration of the execution phase has more of an impact. Consider the GBP 3 billion capex of Dogger Bank A. Assuming a linear cumulative consumption of resources, increasing the duration will increase the present value of the capex. Again, this happens because part of the negative cash flow is postponed and as established earlier the effect of delaying a cash flow is a growth rate of $1/(1+r)-1$. In figure 3 we show the effect of assuming different durations of the execution phase. For illustration, we have assumed a discount rate of 10 %. For instance, with a duration of one year, the present value of the investment cost would be GBP 3 billion becomes GBP 3 billion. On the other hand, if the duration was five years, the present value would be GBP 2 501 919 268.

Figure 3: Effect of execution phase duration on present value



The effect of changing the duration of the execution phase on the present value of a capex of GBP 3 billion. An arbitrary discount rate of 10 % is chosen for illustrative purposes. The capex is divided equally across each year of the execution phase.

From Equinor's press release, we know that the capital investment will occur between 2020 and 2026. We have, for instance, assumed that the capex for Dogger Bank B will occur from 2021 to 2023 (three years), but we could also have assumed a longer duration. While it is true that extending the duration of the execution phase will increase the present value of the capex, the stream of revenues would also be delayed, which would decrease the present value of the income. Hence, the aggregate effect on net present value is an empirical question.

3.2 Gross income

According to Equinor's press release, each of the Dogger Bank projects will have a total generating capacity of 1.2 GW. Furthermore, the projects will have a fixed price for the first 15 years of operation. Specifically, Dogger Bank A will have a fixed price of 39.650 GBP/MWh while Dogger Bank B and C will have a price of 41.611 GBP/MWh. From Dogger Bank Wind Farm's official website[6], we learn that the leading capacity factor is 63 %. According to United States Nuclear Regulatory Commission[7], capacity factor is defined as "The ratio of the net electricity generated, for the time considered, to the energy that could have been generated at continuous full-power operation during the same period." According to literature review and preliminary interviews with industry experts, the capacity factor is likely to be lower than 63%. We also have to account for transmission losses. We come back to this in a future paper.

From the DBWF, we also know that the expected lifespan of the wind farm is 25 years. This input parameter is uncertain.

With the provided information we can easily calculate the expected annual income from each project for the first 15 years operation. Income is the product between quantity of power generated and price - $Income = price \cdot quantity$. As price is a known, we only need to determine production. Since price is in GBP/MWh, we need to transform the capacity of 1.2 GW. First, we multiply with a thousand to change from GW to MW, then we multiply with 8 760 (= $24\ hours \cdot 365\ days$), which is the number of hours in a year. This gives us a maximum annual power generation of 10 512 000 MWh. However, it is quite unlikely that the wind farm will be able to continuously operate at peak capacity for 15 years as wind could be either insufficient or too strong to operate safely. Hence, we multiply with the leading capacity factor of 63 %. (This figure is probably too high, but we use it for demonstration purposes). We get an annual income of GBP 262 584 504 for Dogger Bank A – see Equation (7) – and GBP 275 571 344 for Dogger Bank B and C. The difference in income for each project is caused exclusively by differences in fixed price.

[6] https://doggerbank.com/video-library/ 12.01.21

[7] https://www.nrc.gov/reading-rm/basic-ref/glossary/capacity-factor-net.html 12.01.21

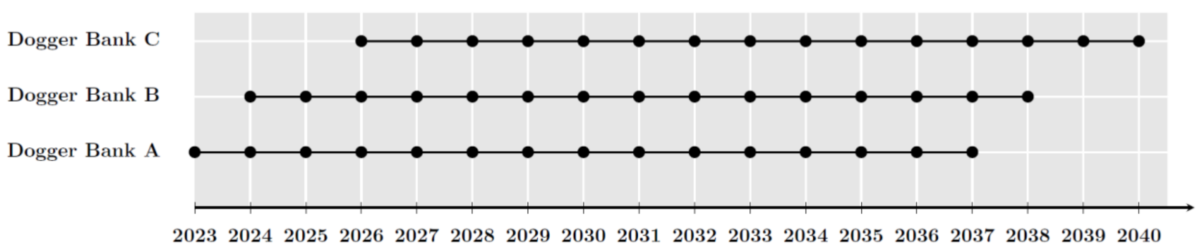
$$\begin{array}{c}\text{Income for}\\ \text{Dogger Bank A}\\ \text{with fixed price}\end{array} = \underbrace{\overbrace{\underbrace{1.2\,GW \cdot 1000}_{\text{Changing from GW to MW}} \cdot \underbrace{(24\,hours \cdot 365\,days)}_{\text{Hours in a year}} \cdot \underbrace{0.63}_{\text{Leading capacity factor}}}^{6\,622\,560\,MWh}}_{\text{Estimated annual production}} \times \underbrace{39.650\,GBP/MWh}_{\text{Fixed price}} = 262\,584\,504\,GBP \qquad (7)$$

The only source of uncertainty regarding the income for the first 15 years pertains to the leading capacity factor. A higher (lower) capacity factor will result in a higher (lower) income. Beyond the initial 15 years, the price will also be uncertain.

Additional to the uncertain elements of the income, the present value of the income is subject to the uncertainty of the timing. Delaying the operation will decrease the present value of the income. As stated by Equinor's press release, Dogger Bank will begin operating in 2023. The exact day and the time required before the entirety of the wind farm to start operating is unknown. For simplicity, we will assume that initiation is instantaneous. We will also assume that operations start in the beginning of the year[8].

As previously cited, in an interview with SSE[9], it comes to light that, "Dogger Bank A and B are being constructed at the same time […]". However, only Dogger Bank A has been stated to begin its operation in 2023. Dogger Bank B will presumably not start operating in 2023. Given the information from the interview with SSE, we will assume operations are initiated in the beginning of 2024. In the very same interview, it is stated that "The wind farm is slated for full commissioning in 2026." Consequently, we will assume that the last project, Dogger Bank C, will start generating electricity in the beginning of 2026. The outlined time line is summarized in Figure 4.

Figure 4: Assumed timeline for initial 15 years of operation



As noted earlier, the expected lifespan of the wind farm is 25 years. The fixed price, however, is only valid for the initial 15 years of operation. The final 10 years of operation is subjected to market prices.

3.3 Operational expenditure

The annual OPEX (operation and maintenance expenditure) throughout the Dogger Bank Wind Farm's lifespan is an essential component in our net present value analysis. For offshore wind farms, OPEX typically includes components such as regular maintenance, repair, spare parts, access to platform and turbines, insurance and administration. Analysis of past offshore wind farm projects suggested a stable relationship between lifetime OPEX and the project's CAPEX. An insightful analysis by Ng and Ran (2016) consider 45 large European offshore wind farms, which in 2013 accounted for 96 % of all offshore wind power capacity. Data for these wind farms were collected from Risø DTU, KPMG and 4C. Ng and Ran (2016) makes three remarks that are of particular interest for our analysis:

- "Lifetime OPEX of offshore wind is close to 90% of its CAPAX." (Ng and Ran, 2016, p. 6);
- "Next to investment cost, operation and maintenance (O&M) costs constitute a sizeable share of the total costs of an offshore wind turbine. Thus, O&M costs may easily make up 25-30% of the total levelised cost per kWh produced over the lifetime of the turbine." Ng and Ran (2016, 2016, p. 16); and
- "In the past, lifetime average O&M cost have been estimated spanning a broad range from 15 to 49 €/MWh." Ng and Ran (2016, 2016, p. 16)

While these three pieces of information might seem inconsistent, they are actually coherent. Let us demonstrate this by taking a look at Dogger Bank A. As established, the CAPEX for each of the three projects constituting the Dogger

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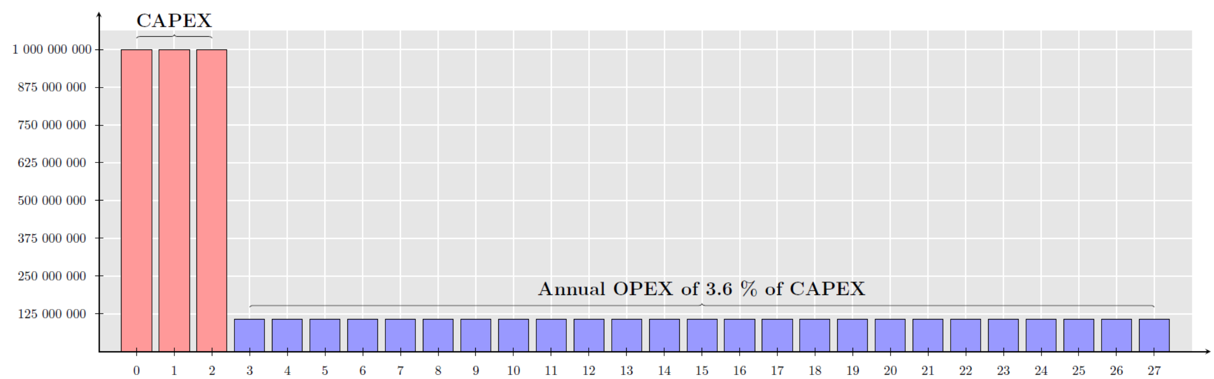
[8] Arguably, in the absence of information, each day is of equal probability. Hence, the expectation would be that the wind farm is only operational for half a year. By assuming that operations start at the beginning of the year, the present value becomes higher. However, this effect is neglectable.

[9] https://www.offshorewind.biz/2020/11/26/dogger-bank-owners-close-largest-ever-offshore-wind-project-financing/ 11.01.21

Bank Wind Farm is GBP 3 billion. The most parsimonious scenario would be to assume uniformity in the OPEX. That is, if we assume an aggregate OPEX equal to 90 % of CAPEX, this would correspond to an annual, average OPEX of 3.6 % ($= 90/25$) of CAPEX throughout the 25-year lifespan. More specifically, the annual OPEX for each project is GBP 108 million ($= GBP\ 9\ billion \times 3.6\%$) under this set of assumptions. The cost profile is shown in Figure 5.

Figure 5: Dogger Bank A cost profile



The cost profile of the Dogger Bank A project. Red bars represent CAPEX and blue bar denotes OPEX.

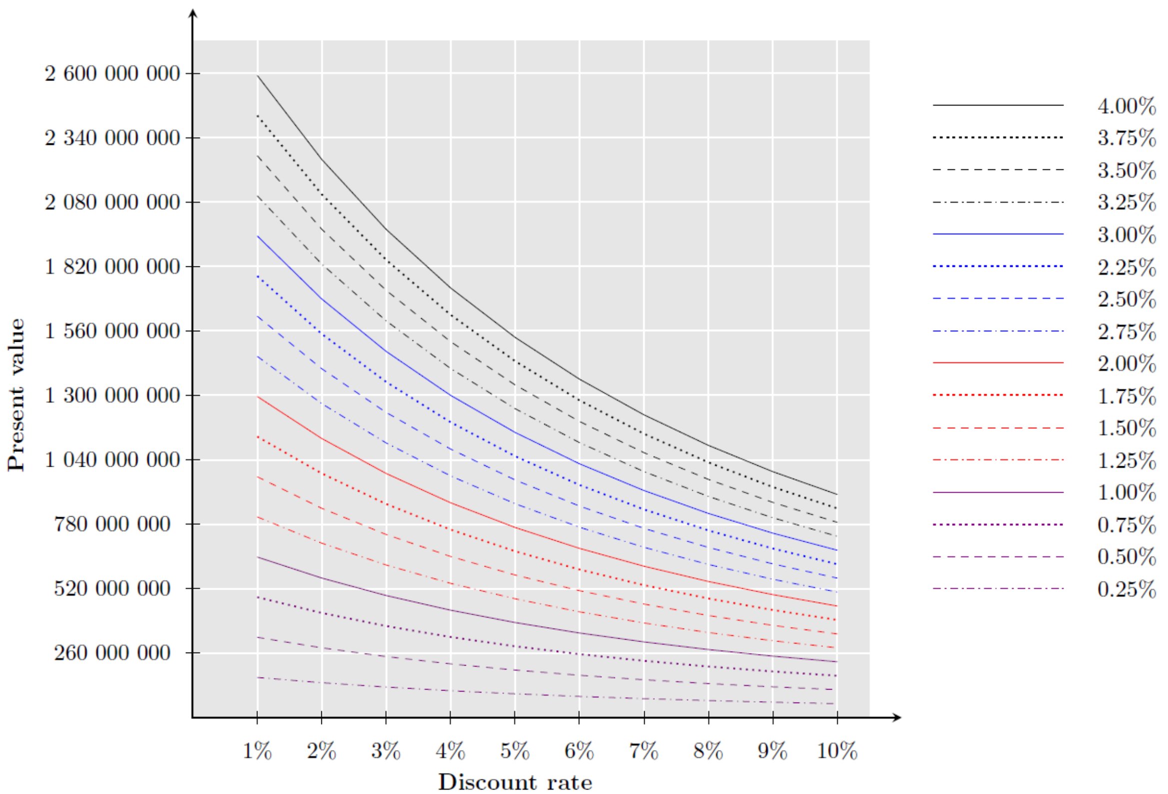
In this scenario, the present value of the life-time OPEX can be calculated using the annuity Equation. Let the present value of an annuit be denoted as $a(CF, T, r)$ where CF represent the annual cash flow, T the number of time periods where the cash flow is received and r the discount rate. The present value of the annuity is then given as in Equation (8).

$$a(CF, T, r) = \frac{CF}{r}\left(1 - \frac{1}{(1+r)^T}\right) \tag{8}$$

For Dogger Bank A, in accordance with our previously established assumption, CAPEX will be invested from 2020 to 2022. In other words, in timer period 0, 1 and 2. The OPEX will consequently start to occur in 2023 or time period 3. To find the present value of the lifetime OPEX, we need to multiply the present value of the annuity ($a(CF, T, r)$) with $1/(1+r)^2$. Applying the outlined Equation gives us a present value of around GBP 810 182 084 of the life time OPEX when assuming a generic discount rate of 10%. Dividing OPEX's present value with the present value of CAPEX gives a ration of around 29.62 %. Dividing lifetime OPEX and expected lifetime energy generation gives 16.31 GBP/MWh. Hence, as shown, by using the "90% of CAPEX" statistics, both the ratios we achieve are consistent with the statistics presented in Ng and Ran (2016).

The present value of the lifetime OPEX is quite sensitive to both the choice of discount rate and percentage of CAPEX that denoting the annual OPEX. As can be discerned by Equation (8), increasing the former leads to a decrease in present value of lifetime OPEX. In other words, net present value of the project increases. Increasing the latter, however, increases present value of the lifetime OPEX and decreases the project's net present value. Figure 6 showcase the present value's sensitivity to these two input variables.

Figure 6: Present value of lifetime OPEX for Dogger Bank A

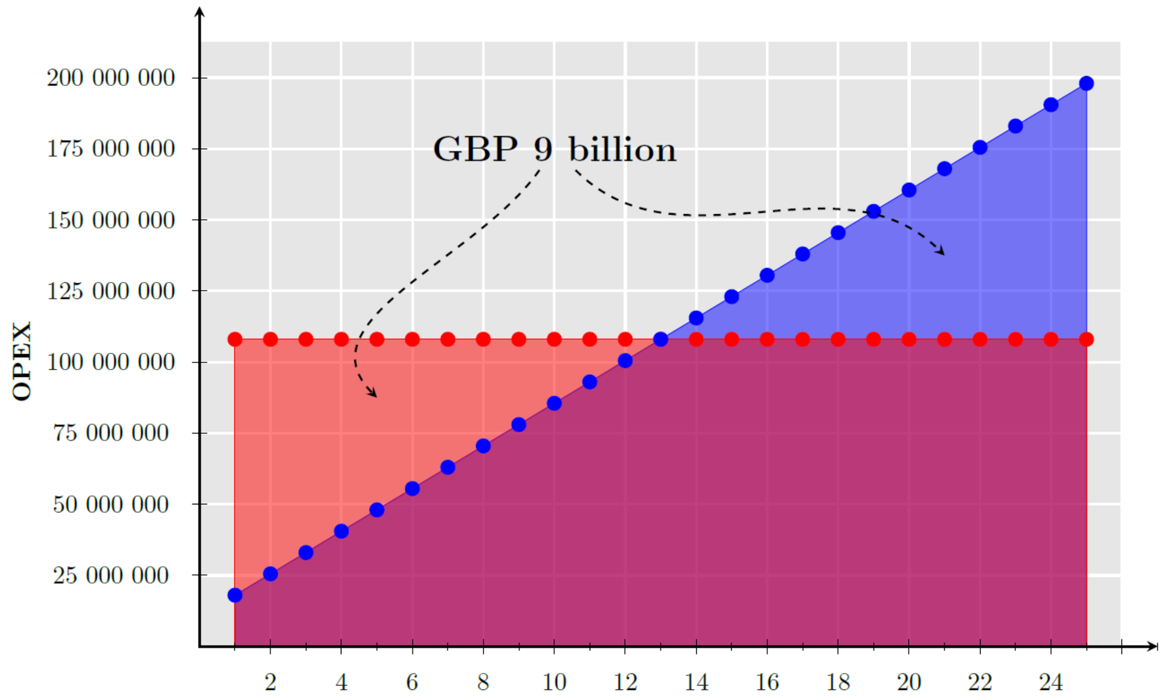


The present value of the lifetime OPEX across different discount rate for Dogger Bank A. OPEX is calculated as a percentage of CAPEX and remains unchanged throughout the entire lifespan. Each curve represents a different annual CAPEX percentage from that constitutes the OPEX. The present value is calculated as follows:

$$PV = \left(\frac{OPEX}{r}\left(1 - \frac{1}{(1+r)^T}\right)\right) \cdot \frac{1}{(1+r)^2}.$$

A noteworthy shortcoming of our coverage of the OPEX is the assumption of uniformity. It is well known that annual OPEX is changing throughout the life. More specifically, it starts relatively low and increases as the wind farm matures. According to Ng and Ran (2016, 16): "[…] O&M costs may easily make up 25-30% of the total levelised cost per kWh produced over the lifetime of the turbine. If the turbine is fairly new, the share may only be 20-25%, but this might increase to at least 30-35% by the end of a turbine's lifetime." By assuming a stable annual OPEX, we run into the same issue we experienced with applying linear cumulative CAPEX rather than an S-shaped curve. Even with a fixed lifetime OPEX, the timing will influence the present value. Delaying a negative cash flow will increase the net present value. Under our set of assumption, a part of the OPEX will occur too late (increases present value) and another part will occur too early (decreases present value). Due to the asymmetric effect on present value of delaying and advancing a cash flow, the present value of OPEX will be higher when assuming a constant OPEX. For Dogger Bank A the present value of a stable annual OPEX of GBP 108 million (2.6% of CAPEX) is GBP 810 182 084 when assuming a discount rate of 10 percent. There is no shortage of possible scenarios for an increasing OPEX. In the absence of further information, the most parsimonious scenario would be to assume a linear curve. Even then, a slope and initial OPEX must be determined. For illustrative purposes, the initial OPEX could be 0.6% of CAPEX and then increase by 0.25 percentage points. The undiscounted sum of both these scenarios would then be a lifetime OPEX equalling 90% of CAPEX. See Figure 7 for an illustration. With this particular slope and initial OPEX, we get a present value of GBP 554 636 136 when assuming a discount rate of 10%. In other words, assuming constant OPEX gives a roughly 46% higher present value than assuming the outlined scenario for increasing OPEX. This difference will increase if we assume a steeper slope or a higher discount rate.

Figure 7: Comparison between uniform and increasing OPEX for Dogger Bank A



4. Results

Key input parameters for a cost-benefit calculation for a windfarm is the size and scheduling of the capital expenditure, the capacity factor, the electricity price after the CfD has expired, the discount rate and the decommissioning cost. The net present value is highly sensitive to the choice of discount rate. As previously established, Dogger Bank Windfarm will be operating under a fixed price regime for the initial 15 years of operation. As such, it is reasonable to operate with a considerably lower discount rate. We argue for using two different regimes of discount rate – one for the fixed price period and another for when the wind farm is subjected to market prices. Both petroleum and electricity prices are volatile. The former is nonstationary while the latter is stationary. In short, whether the projects will be profitable, in terms of net present value, will to a large extent depend on beliefs regarding the market price of electricity 15 years from now and how low the company is willing to go regarding the hurdle rate.

5. Conclusions

Our analysis elucidates important aspects of the business economics of offshore wind farm project by using Dogger Bank as a case study. With our principal analysis, we have revealed a knowledge gap in regard to the capacity factor and the future market price. More research is needed on these two topics. To ensure the continued participation of oil and gas companies as well as other private companies in the shift toward a greener energy mix, we argue that continued support from governments in terms of the CfD is needed. Without guaranteed prices the first 15 years of operation, funding cost would rise substantially. Continued innovation is needed to ensure cost reduction.

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