Feasibility report for an offshore energy park in the Severn Estuary

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Abstract

The aim of this project was to conduct a feasibility assessment to see if wind and tidal turbines could be used in a specific portion of the Severn Estuary to generate power for the city of Cardiff. The domestic electricity usage in Cardiff for the year 2019 was 2.4TWh (Regen 2022). Numerous things had to be considered, such as the amount of power that could be generated using different types of wind and tidal turbines, the tower and foundation designs, the environmental impact of these technologies, the structural health monitoring that would be in place, and a cost analysis of the technologies had to be considered.

1. Introduction

Wind energy has grown in popularity for a variety of reasons, one of which is the UK government's goal of producing 50GW of energy from offshore wind, which will be accomplished through a £160 million pledge for offshore wind power as a means of 'building back greener' following the Covid-19 pandemic (Department for Energy Security and Net Zero and Department for Business, Energy & Industrial Strategy 2022). The Severn Estuary is the second largest estuary in Britain, with some of Europe's greatest tidal ranges and depths reaching up to 50m near the estuary's mouth (where it meets the Celtic Sea and Atlantic Ocean). Additionally, Wales offers an abundance of wind resources in offshore locations, as well as adequate port, transportation, and grid facilities in both North and South Wales.

Figure 1 depicts the allowed location of the energy park. To begin, the total amount of energy that could be generated by wind and tidal turbines in the designated park area (considering environmental restrictions, discussed in detail later) had to be evaluated to see whether it would be worthwhile to install these technologies.

Figure 1. Area for the energy farm (Severn Estuary) approximately 200km^2.

1.1 Wind Energy

An estimate of wind energy was calculated using Wentloog wind speed data provided by Cardiff University's research team. The Wentloog data consists of a list of minimum and maximum wind speeds for Wentloog from 2014 to 2019 in ten-minute intervals. The average wind speed in this ~200km^2 area is between 8–10 m/s. The optimal upstream wind speeds were found for 600kW, 1.3MW and 2MW turbines by overlying the power generated graph onto the Weibull distribution graph, as shown in figure 2. It was found that the upstream wind speeds are 9m/s, 10m/s, 9.5m/s for the wind turbines respectively.

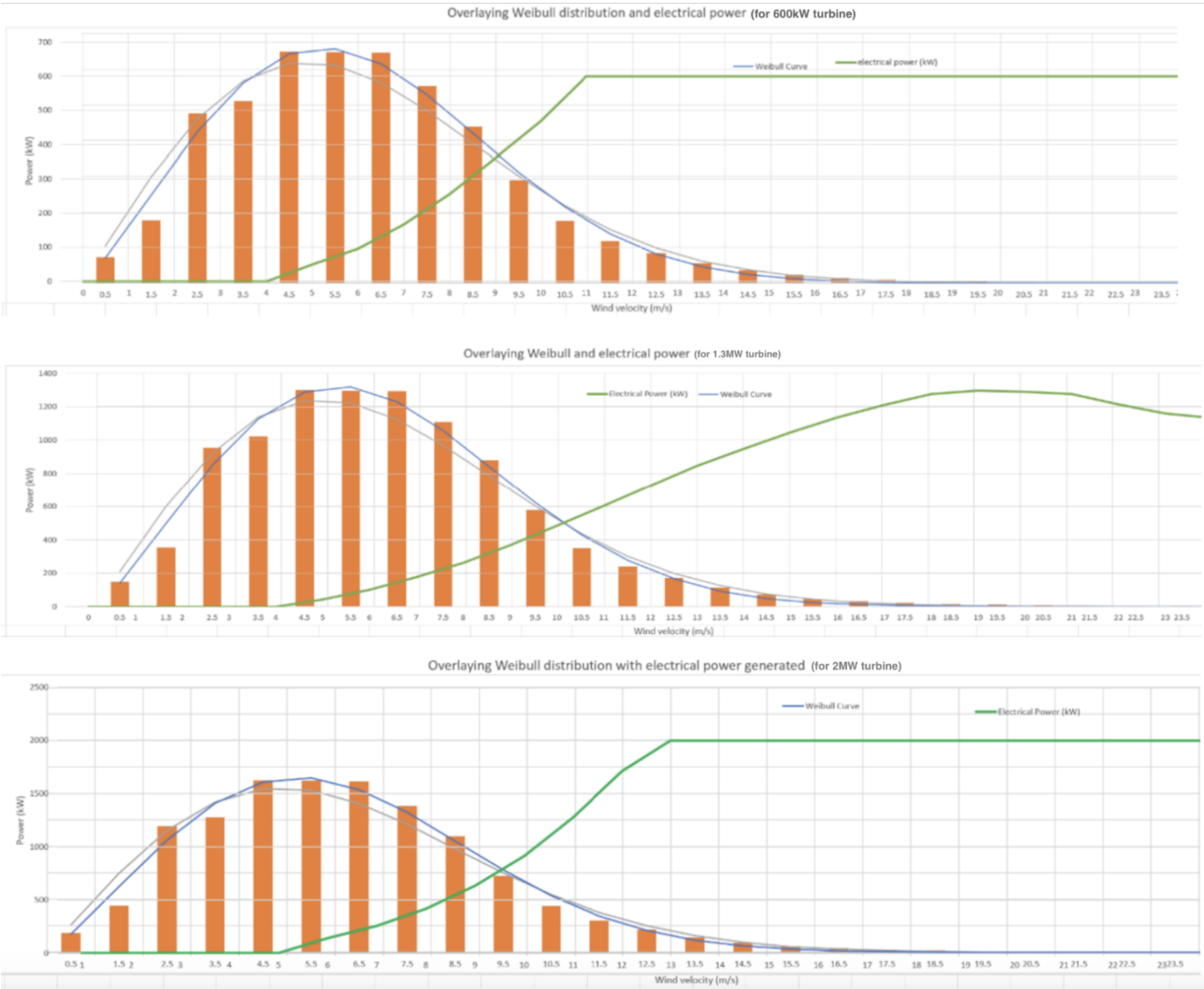

Figure 2. Overlaying the Weibull distribution graphs and the maximum power generated graphs for the 600kW, 1.3MW, and 2MW turbines respectively.

Several studies suggest that the shape of a wind farm and distance between turbines have a major impact on its power production (Xu et al. 2022). To determine the optimal distance between each consecutive turbine and then the total power generated, the wake effect had to be taken into consideration using the turbine array principle illustrated in figure 3, where every subsequent turbine uses the slightly reduced upstream velocity due to the wake generated.

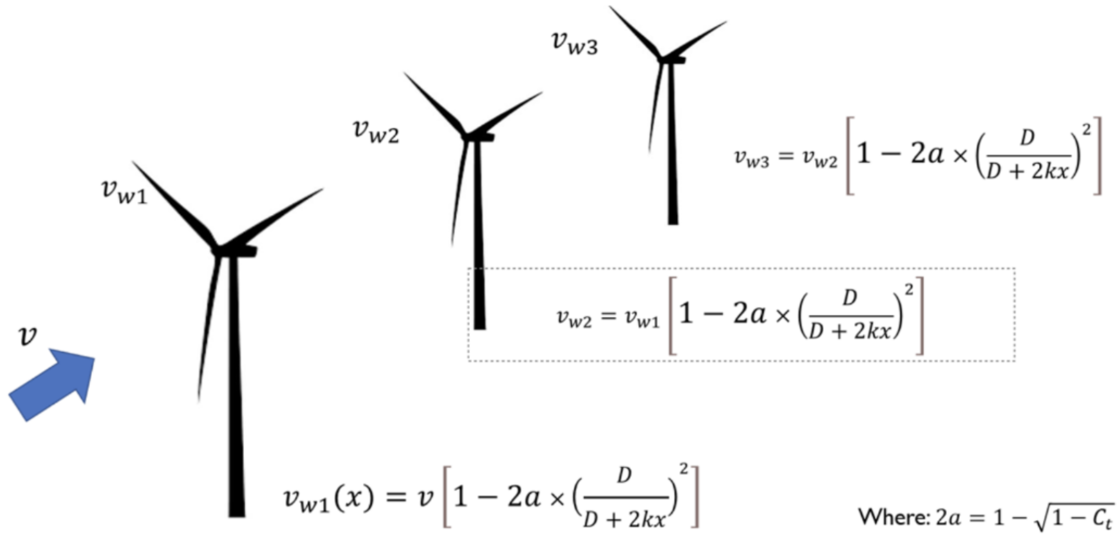

Figure 3. Turbine array- directly downstream (Cardiff University).

Once all the velocities were found, the total power generated was calculated for many different turbine arrangements (staggered and evenly spaced) using equation 1.1.1.

$$P(v_{wn}) = C_p \frac{1}{2} \rho A (v_{wn})^3$$

Equation 1.1.1

Where C_p is the power coefficient of the turbine taken as 0.45, ρ is the air density taken as $1.2kg/m^3$, A is the rotor swept area, and v_{wn} is the upstream velocity which is affected by the wake effect.

Thus, the optimal distance between turbines and the turbine type was determined. It was found that the layout which generated the highest amount of electricity was the one shown in figure 4, using 28 irregularly spaced out 2MW turbines which would generate 92.5GWh/year. In the figure, the red dots represent the offshore wind turbines. The optimal spacing between the turbines is given in table 1.1.1.

It was also decided to use monopiles as the foundation type for the turbines, as they are the leading approach for offshore wind turbine foundation designs. The industry leans towards using monopile foundations as in 2019, 81% of all offshore turbines in European waters were supported by monopiles (Orsted 2022). This is because monopile foundations are reliable and have a relatively easy installation process. This foundation type is applicable in water depths up to 30m, with the foundation depth itself spanning up to 15m below the seabed.

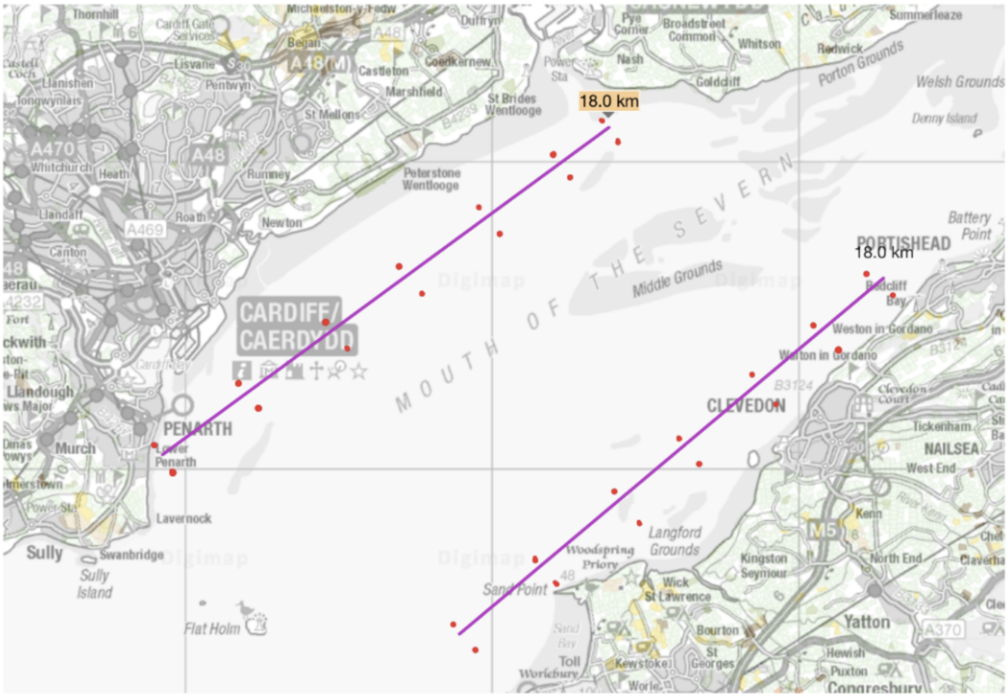

Figure 4. Optimal irregular arrangement of 28, 2MW turbines.

Table 1.1.1. Power generated and distance of irregularly placed 2MW turbines.

Turbine number	Distance (m)	Velocity (m/s)	Power (W)	Total power with 4 arrays (MW)	Total power per year with 4 arrays (GWh/year)
1	0	9.5	1,163,590.8	26.4	92.5
2	3400	9.25	1,074,124.6		
3	3300	9	989,366.0		
4	3000	8.96	976,233.0		
5	3200	8.7	893,690.6		
6	3000	8.42	810,150.5		
7	2100	8	694,863.4		

The parameters of the 2MW turbine are a hub height of 61.5m, and a rotor diameter of 80m. This layout results in the highest power generated using the least amount of turbines than any other layout tested.

1.2 Tidal Energy

The Severn Estuary has a large tidal range and high potential for tidal energy production, which is a very desirable energy source due to its predictability. However, tidal turbines need to experience velocities greater than 0.75m/s to generate usable energy, as well as not be positioned within 25% of the sea-bed depth due to high tidal shear velocities which can damage the turbine (Cardiff University). Additionally, there are numerous environmental considerations and shipping lanes restrictions which need to be taken into account. The draught of the ships poses a significant constraint, as the greatest depth of draught is 14.5m for ships docking at Bristol's Portbury (Severn Estuary Partnership 2022), while the deepest part of the estuary for the area considered is 20m.

Transect data was collected on the West side of the estuary, shown in figure 5, by another Cardiff University research team. To determine the power produced by a tidal turbine, any current velocities below 0.75m/s were removed from each transect due to the assumption that current speeds below 0.75m/s do not generate any useful power.

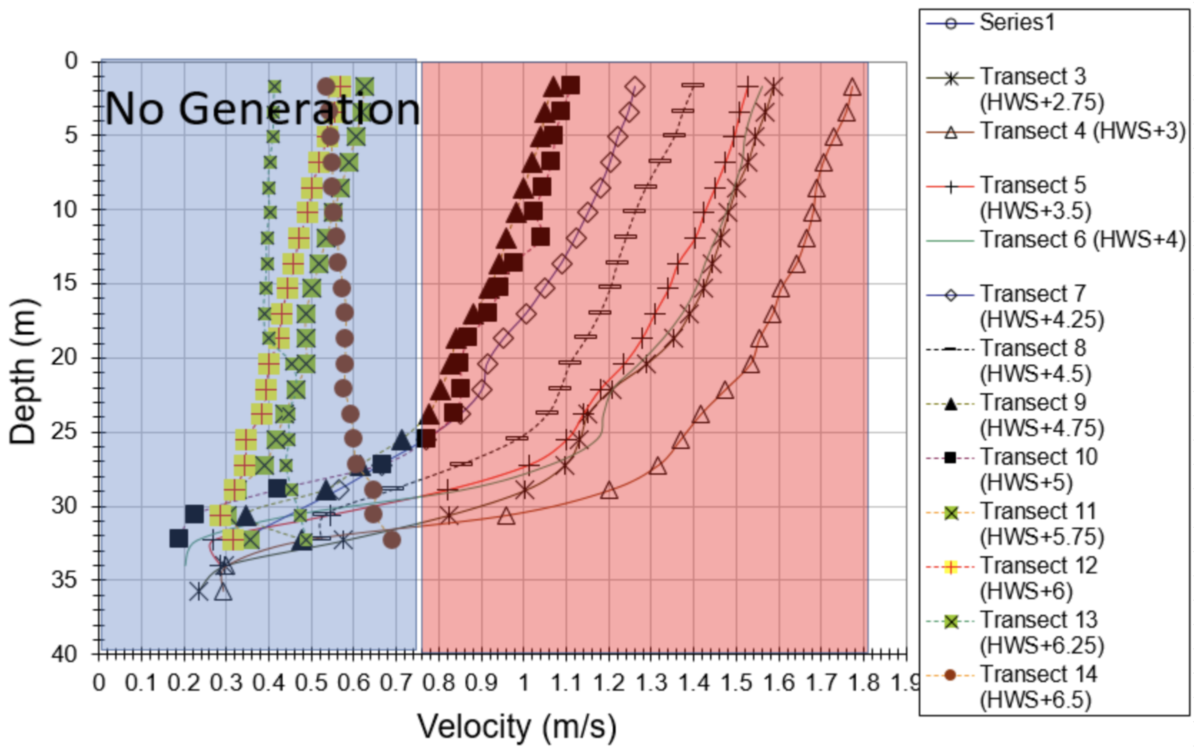

Figure 5. Average velocity profiles for each transect of the filtered data (in the Severn Estuary).

Subsequently, the theoretical power generated at every depth for each transect was calculated using equation 1.2.1.

$$P = 0.5 \times C_p \times \rho \times A \times U^3$$

Equation 1.2.1

Where C_p is the power coefficient ($C_p = 0.4$), ρ is the density of the water ($1000\ kg/m^3$), A is the swept area of the blade ($78m^2$), and U is the stream velocity.

Once the theoretical powers were calculated, the approximate time for each profile was required to obtain the turbine kWh per day for ¼ of a tidal cycle; this was done by taking the difference between successive 'time past High Water Springs (HWS)'. Knowing the approximate time per profile, the energy generated per day was found using equation 1.2.2.

$$E = 4 \times P \times t$$

Equation 1.2.2.

Where P is the power generated at a specific depth, and t is the approximate time for a profile.

The energy generated was multiplied by 4, as there are 4 tidal cycles per day. Adding all the values of the energy generated per day for each depth gave the daily power generated by one turbine at a given depth. Table 1.2.1 shows the power generated per day for one turbine at each depth. This was then multiplied by 365 to get the power generated in one year by a turbine at the specific depths.

Table 1.2.1. Daily power generated by one turbine at each depth.

Depth (m)	Daily power generated by 1 turbine (kWh)
0	0
1.7	524.6
3.4	546.8
5.1	524.6
6.8	503.8
8.5	481.5
10.2	462.9
11.9	448.6
13.6	417.7
15.3	392
17	367.7
18.7	336.9
20.4	309.9
22.1	277
23.8	249.2
25.5	214.5
27.2	153.8
28.9	97.6
30.6	36.3
32.3	--
34	--
35.7	--
37.4	--
40	--

As can be seen from table 1.2.1, the highest power generated is 546.8kWh at a depth of 3.4 metres, however it is not possible to place the tidal turbine at that position due to shipping restrictions. Thus, the next highest power generation where it is possible to position the rotor is at a depth of 15.3 metres with 392kWh generated in one day. Since only around 18 turbines could be positioned in the given location, the maximum amount of power produced would be 2.5GWh/year of electricity. This would only cover 0.1% of Cardiff's yearly energy demand, making the tidal turbines not worth the financial investment.

2. Environmental Impact Assessment

The objective of the Environmental Impact Assessment (EIA) is to determine the feasibility of an offshore power generation farm in the Severn Estuary. It evaluates the options of wind and tidal energy generation giving both the positives and negative impacts. For the design and construction of this energy farm, various regulations and standards must be followed.

The Severn Estuary's habitats include sandbanks and mudflats, rockpools, saltmarshes, and islands. These provide habitat for a diverse range of wildlife, including many rare or endangered species. Most of these unique environments are protected by regulations and legislation, allowing them to thrive. There are three types of habitat in the estuary: subtidal, intertidal, and supratidal (Severn Estuary Partnership 2021). The subtidal ecosystem is immersed in water and is home to a diverse range of fish species. Supratidal habitats are found on dry land, and the estuary is home to a variety of birds and mammals. The intertidal ecosystem is submerged during high tide and exposed during low tide. Because of the estuary's vast tidal range, the intertidal habitats of sandbanks, rocky platforms, mudflats and saltmarshes produce a diversified ecosystem for many species to live in, which is one of the reasons for the multiple protection zones in the area (Severn Estuary Partnership 2021).

The main environmental concern regarding air in regards to wind turbines is the emissions produced during manufacturing, transportation, installation and decommissioning. It is estimated that wind energy installation produces 12g of CO2eq/kWh along with various nitrogen oxides and sulphur dioxide. Though, when compared to the current main energy source in Wales, natural gas emits an estimated 185g of CO2eq/kWh, so the savings would be substantial (National Grid 2022). Instead of using an already limited resource, the Severn Estuary project optimises the natural resource of wind and air, assisting Wales on its clean energy goals to generate 70% of its electricity by renewable sources by 2030 (GOV.UK 2023). There are a few ways in which to reduce the carbon emissions produced by wind turbine production and installation. One such way would be to use locally sourced materials which would significantly reduce the distance they would have to travel therefore reducing the carbon dioxide released into the atmosphere by transportation. In addition, using recycled materials, rather than producing more could reduce the amount of greenhouse emissions at the production stage.

Noise pollution is a concern for both wind and tidal energy production. Many of the associated noise issues have a direct influence on the species within the Severn Estuary's numerous protected zones. The majority of these negative effects decrease the survival rate of marine life. The current design for the energy park involves 28 monopile wind turbines. Whilst monopile towers are the most convenient and cost efficient for the project, they have a large environmental impact to the surrounding marine life. Monopile towers are very loud and disruptive to construct, with significant drilling and driving of the piles into the seabed. The noise during construction can travel great distances throughout the estuary, causing changes to swimming and schooling behaviour, stress levels and feeding rates to many of the species located there (Mooney, Andresson and Stanley 2020). Total mitigation, and therefore total protection of the species within the estuary is not currently feasible, thus the construction of the energy farm would not be able to go forward in the specified location.

There are also very limited positive impacts of this project when considering water. The wind turbines impact the natural hydrodynamic flows and alter the flow of suspended sediment potentially changing habitats, which is heightened when using the monopile foundations in the current design, as demonstrated by LafargHolcim (2021). With this comes change in water quality and conditions which are especially hard to mitigate, so monitoring would be essential. There are limited studies on tidal turbines and the magnitude of their impact, especially in an environment such as the Severn Estuary with such a large tidal range and vast number of habitats. This makes mitigation of the known issues very difficult due to the limited technology available.

There are many other users within the estuary, including busy shipping routes and numerous tourism sites. Building the energy farm would majorly disrupt these other projects as many would have to temporarily stop during construction, which is not feasible.

On the other hand, the Severn Estuary energy park project would bring many benefits to the local communities with an increase in employment, infrastructure, and a renewable source of energy. However, there are still some serious disadvantages due to the disruption created during the construction and decommissioning phases of the energy farm. Currently, for the energy project, there are significantly more negative impacts than positive ones. Under the laws that cover the Severn Estuary region, it is required that the protected species inhabiting the estuary are not disturbed, injured or killed, and their resting and breeding places should remain unobstructed or damaged (GOV.UK 2023). It is thus suggested that the farm be positioned in a location with deeper water depths as well as where fewer protected species and habitats exist. A better location for the proposed energy farm would be past Flat Holm and Steep Holm Islands, closer to the river’s mouth (shown in figure 6). This area has water depths up to 30m and also higher wind speeds (up to 11m/s), which would increase the efficiency of the wind turbines allowing for a higher energy production.

Figure 6. Suggested area for the energy farm, past Flat Holm and Steep Holm Islands.

3. Structural Health Monitoring

Structural health monitoring (SHM) is a very important aspect that should be incorporated in the design of the energy farm in the Severn Estuary as it will reduce the maintenance downtime, reduce the frequency of sudden breakdowns, and keep the power generation more dependable. SHM systems will help to reduce an offshore turbine's levelised cost of electricity (LCOE) by increasing management efficiency, making it more financially appealing to many investors and governments (Martinez-Luengo, Kolios, and Wang 2016).

The three most commonly used approaches/sensors to monitor the health of wind turbine components are:

1. Acoustic Emissions (AE) analysis- AE sensors use sound level meters to capture the sound produced by various components. The sensors used are usually piezoelectric acoustic wave sensors, which apply an oscillating electric field in order to generate a mechanical wave (Salameh et al. 2018). AE sensors are typically used for crack monitoring on blades and the tower.
2. Vibration analysis/accelerometers- these sensors typically monitor the vibrations of rotating components throughout the drivetrain. Vibration analysis is the most commonly used condition monitoring technique as all rotating machinery has a characteristic vibration and when there is a fault/defect in the component, the vibration profile changes. Accelerometers should be located on all mechanical

components, such: the main bearing, planetary gears, gearbox, shafts, and generator (Samimy & Rizzoni 1996).

3. Tachometer/Encoder- these are speed sensors used to measure the velocity of rotating components. A tachometer sensor is essentially a magnetic field sensor which works on the principle of relative motion. A pulse is generated every time a magnet on the shaft passes in front of the sensor. It is cheap and simple to install and works well in wind turbine applications as the conditions are not always ideal. These sensors should be located on low-speed and high-speed shafts (Heidenhain 2023).

All these sensors will be connected to a data acquisition system (DAQ) through appropriate wiring which collects the data in real time. A DAQ system analyses the data obtained from the sensors and identifies patterns or abnormalities that may indicate a problem with the equipment. The system can also be used to trigger alarms when certain thresholds are surpassed. The DAQ system usually consists of data capture, signal conditioning, data processing, data analysis and data communication (Swiszcz et al. 2008). Data capture involves capturing the required data via the sensors deployed on various components of the wind turbine. Signal conditioning can include things like amplifying weak signals, filtering out noise or undesirable frequencies, and converting analogue signals to a digital format for further processing. Data processing entails performing a series of operations to extract useful information from the data collected. Lastly, the information gathered is sent to systems/users for remote monitoring, assessment and decision-making.

In conclusion, SHM will be incorporated in the design of the energy farm as it will significantly reduce costs by allowing for the early detection of any anomalies, it will provide better maintenance planning (condition-based maintenance), it will prevent catastrophic failures, and will allow for remote monitoring and diagnostics. Early identification of faults enables a quick intervention decreasing the risk of future damage and costly downtime. Condition-based maintenance optimises maintenance schedules by reducing unnecessary servicing resulting in cost savings through reduced downtime and maintenance expenses. Remote monitoring and diagnostics are possible with SHM, allowing for continuous data collection and a remote assessment of the wind turbine's condition. This eliminates the requirement for physical access to the turbine, which results in cost savings from reduced travel, and maintenance team deployment.

4. Cost Analysis

Conducting a cost analysis of the proposed energy farm is a multi-stage process which consists of determining the payback period and the levelised cost of energy. Firstly, the general data for the current wind farm proposed must be determined and the relevant assumptions made. Table 4.1 below shows the general data for the wind farm that will be used in the subsequent calculations.

Table 4.1 General plant data for the proposed wind farm

General Plant Data	
Region	Severn Estuary
Number of Turbines (Units)	28
Rated Power (MW)	2
Rated Capacity (MW)	56
Average Water Depth (m)	35
Turbine Operation Height (m)	80
Capacity Factor (%)	23
Load Factor (%)	40
Annual Mean Wind speed (m/s)	9.5
Annual Power Generation (GWh)	92.5
Distance to Cardiff shore, grid, port (km)	3km
Distance to Bristol shore, grid, port (km)	7km
Length of all cables	151km
Site Soil Condition	Gravel (silt/clay)
Sub-Structure Type	Monopiles
Estimated Plant Lifetime (Years)	20
Construction period (Months)	24-36

The key assumptions made were as follows:

- Commissioning and decommissioning of the wind farm will both take 2 years
- The wind turbines will operate for 20 years
- Energy generation only occurs after installation and none during decommissioning
- The annual energy generation of the turbines is constant for their entire operational phase
- The turbine efficiency is constant
- A fixed discount rate of 6% used (Grant Thornton 2019)

Offshore wind farms are difficult to accurately cost up due to several factors which are location-based specific, such as the exact location in relation to the shore, the environmental factors, as well as the depth of the water, weather and sea conditions. First, the levelised cost of energy (LCOE) was estimated using a method proposed by Maienza et al.

LCOE calculates how much money must be made per unit of electricity (MWh) in order to cover the lifetime costs of the system. This includes the maintenance costs, initial capital investment, the cost of fuel for the system (if any), operational costs and the discount rate. LCOE is a method of predicting whether a company will build a project or not, since if the project will not break even, it will not be built. There are a number of ways of calculating LCOE, however the most straightforward method is by using equation 4.1.

$$LCOE = \frac{CAPEX + OPEX + DECEX}{AEP}$$

Equation 4.1

Where CAPEX is the capital expenditure, OPEX is the operational expenditure, DECEX is the decommissioning expenditure, and AEP is the annual energy production (in MWh). It must be noted that LCOE estimates are highly sensitive to the data and assumptions made, thus it will only be used as a tool to help see if the value obtained is close to the expected value.

The contributions to CAPEX are mainly calculated analytically and/or as a function of the installed power of the wind farm. The pre-development and energy survey costs necessary for the development of the wind farm are outlined in table 4.3 and amount to a total of £5 million. The cost of wind turbines is usually expressed as a function of rated power and does not depend on the type of installation. Using a linear regression model on the available dataset containing prices of wind turbines with rated power between 2MW and 10MW, the cost of a wind turbine (in millions of euro) is given by equation 4.2 (Maienza et al. 2020).

$$C_T = (1.6 \cdot p_T - 1.9) \cdot n_T$$

Equation 4.2

Where p_T is the installed power (MW) of one turbine and n_T is the number of turbines in the farm. The offshore wind farm in question consists of 28, 2MW turbines, so the cost of the wind turbines is:

$$C_T = (1.6 \times 2 - 1.9) \times 28 \Rightarrow C_T = € \ 36.4 \ million \approx £32 \ million$$

The cost of the transmission system includes the: array cables, offshore export cables, and the onshore substation. Thus, the transmission system cost, C_{TS}, can be expressed using equation 4.3 (Maienza et al. 2020).

$$C_{TS} = C_c + C_{sp}$$

Equation 4.3

Where C_c is the cost of the export and array cables, and C_{sp} is the protective equipment (seals, bend restrictors, etc.) needed to protect the cables. Table 4.3 shows the cost of cables for offshore wind farms (£ /MW) (BVG Associates). The wind farm in the Severn Estuary has a total of 56 MW of turbines. Thus, the total cost of all the cables and cable protection is £9.3 million.

The average labour cost details for offshore wind turbine farms are given in table 4.2 (Maienza et al. 2020).

Table 4.2 Labour cost details.

	Unit	Value
Hourly labour rate for CAPEX activities	€/h	27
Technician daily cost for corrective maintenance	€ / day	200

The total offshore construction time is around 10 days per turbine (9 hour working days), thus a total cost of €68,040; approximately £60,000 is required to install all 28 turbines (Offshore wind installation vessel time per turbine 2022). Assuming a total of 30 days a year are needed for corrective maintenance, an additional £5500 must be spent.

The total installation costs consists of the individual costs for the installation of the wind turbines (includes the cost of the onshore substation construction, onshore export cable installation, offshore cable installation, cable burial etc.). For the Severn Estuary wind farm, it was found that the total installation cost is approximately £34.4 million.

In conclusion, the total CAPEX expenditure is: **£80.7 million.**

The contributions to OPEX are also calculated analytically as a function of the installed power of the wind farm (Maienza et al. 2020). Operating expenditures consist of operational and maintenance expenditures. Operational expenditures comprise of the seabed rental cost, insurance, onshore and offshore logistics, grid access fees, etc. Using the data form table 4.3, it was determined that the total operational costs over the 20 years will be £25.2 million. Maintenance expenditures are split into direct and indirect costs. Direct costs include all actions aimed at avoiding failure of a component and its downtime, while indirect costs have a minimum value corresponding to the optimal solution. Using table 4.3, these were found to be £52.2 million.

In conclusion, the total OPEX expenditure over the 16 operational years is: **£77.4 million**.

Lastly, DECEX are the costs associated with decommissioning and site clearance (the final stages of the project's life), because the farm's components must be dismantled. DECEX includes the cost of the turbine, foundation, cable and substation decommissioning. Using table 4.3 the total cost of decommissioning of the wind farm was found to be £18.5 million.

In conclusion, the total DECEX expenditure is: **£18.5 million.**

The annual energy production in MWh over the 16 operational years of the wind farm is found by: $92,500 \times 16 = 1,480,000\, MWh$. Substituting the values found into equation 4.1, LCOE was found to be 119.3 £/MWh. The average LCOE for offshore wind farms (in 2022) for them to be profitable is approximately 50 £/MWh (Urquhart 2022). The LCOE value obtained for the wind farm in the Severn Estuary is significantly higher than the expected cost-effective value, suggesting that it would not be profitable to build the wind farm. CAPEX, OPEX, and DECEX would have to be greatly reduced to make the project viable, or the annual energy production would have to be much higher without significantly increasing costs.

Table 4.3. Cost breakdown for wind farm [scaled up for 92.5GWh farm) (BVG Associates)

Category	Rounded Cost (£)
Development and project Management	11,100,000
Development and consenting services (environmental impact assessments, other (includes developer staff hours and other subcontract work)	4,625,000
Environmental surveys (benthic environmental surveys, fish and shellfish surveys, ornithological environmental surveys, marine mammal environmental surveys, onshore environmental surveys, human impact studies)	370,000
Resource and metocean assessment (structures, sensors, maintenance)	370,000
Geological and hydrological surveys (geographical surveys, geotechnical surveys and hydrological surveys)	37,000
Engineering and consultancy	37,000
Other (includes lost projects that occur during development expenditure)	4,995,000
Turbine	9,250,000
Nacelle (bed plate, main bearing, main shaft, gearbox, generator, power take-off, control system, yaw system, yaw bearing, nacelle auxiliary systems, nacelle cover, small engineering components, structural fasteners)	37,000,000
Rotor (blades, hub casting, blade bearings, pitch system, spinner, rotor auxiliary system, fabricated steel components and structural fasteners)	17,575,000
Tower (steel, tower internals)	6,475,000
Other (includes assembly, wind turbine supplier aspects of installation and commissioning, profit and warranty)	3,145,000
Balance of plant	55,500,000
Cables (export cable, array cable, cable protection)	15,725,000
Turbine foundation (transition piece, corrosion protection, scour protection)	25,900,000
Offshore substation (electrical system, facilities, structures)	11,100,000
Onshore substation (building, access and security, other (includes electrical equipment and systems)	2,775,000
Operations base	277,500
Installation and commissioning	60,125,000
Foundation installation	9,250,000
Offshore substation installation	3,237,500
Onshore substation installation	2,312,500
Onshore export cable installation	462,500
Offshore cable installation (cable burial, cable pull-in, electrical testing)	20,350,000
Turbine installation	4,625,000
Offshore logistics (sea-based support, marine coordination, weather forecasting and metocean data)	323,750
Other (insurance, contingency (spent) and construction project management)	19,610,000
Operation, maintenance, and service (per annum)	6,937,500
Operations (training, onshore logistics, offshore logistics, health and safety Inspections, other (insurance, environmental studies and compensation payments)	2,312,500
Maintenance and service (turbine maintenance and service, balance of plant maintenance and service)	4,625,000
Decommissioning	30,802,500
Turbine decommissioning	4,162,500
Foundation decommissioning	6,937,500
Cable decommissioning	12,950,000
Substation decommissioning	6,012,500

Next, the simple payback period was found, defined by equation 4.4. Financial payback is the period a business or plant needs to be operational to recover the cost of the initial investment made (Kagan 2022). It is a means of determining whether a project or venture is economically viable and worth pursuing.

$$Payback\ Period = \frac{Cost\ of\ Investment}{Average\ Annual\ Cash\ Inflow}$$

Equation 4.4

The average annual cash inflow is calculated by deducting yearly operation and maintenance cost from the gross annual income of the wind farm. For the proposed wind farm the cost of investment is estimated to be £80.7 million and the average annual cash inflow is estimated as £6.3 million. Substituting these values into equation 4.4, the payback period for the energy farm in the Severn Estuary is 12.8 years, which is significantly higher than the expected average payback period of around 1 year (Thomson & Harrison 2015).

Taking these values into account, it can be said that the wind farm project in the Severn Estuary should not go forward due to the incredibly high LCOE value and relatively high payback period.

5. Conclusion

In conclusion, the energy park was found to be unfeasible for both tidal and wind turbines for several reasons. The use of tidal turbines in the given location was ruled out early in the design because the area of estuary offering the largest tidal ranges coincided with the busiest shipping routes, as well as only having 5.5m of available space due to the maximum ship draught in the estuary being 14.5m. Additionally, the turbines must be placed above 25% of the water depth due to high tidal shear forces, which would take up 5m leaving only 0.5m of space for the turbines. The large tidal range in the Severn Estuary also means that the tidal turbines would only be working half of the time. Moreover, there are numerous environmental reasons as to why the tidal turbines should not be placed in the area. Thus, it was determined that tidal energy was not feasible for the energy park.

It was also determined that using wind turbines would not be feasible in the given location due to the data used, the environmental impacts, and the cost analysis.The data used to determine the potential energy generated by the wind turbines was from a list of wind speeds from 2014 to 2019 in Wentloog. There are several issues with this data, firstly, the collected data is now almost 4 years old and might no longer be representative of the wind speeds in the area. Secondly, Wentloog is located very close to the shore. The problem with this is that the wind speeds near the shore can sometimes be significantly smaller than those in open sea. Since our wind turbines were placed in open sea (and near Bristol), this data might have given quite inaccurate electricity generation results. Additionally, both the simple payback period and the LCOE value for the wind turbines was found to be inadequate, making the wind farm not profitable.

A more appropriate location for the energy park, however, is one further up the estuary (shown in figure 6). This area has greater wind speeds and water depths, making it better for both wind and tidal turbines. It should also be noted that there are several onshore wind turbines located at Avonmouth docks, suggesting there is potential in harvesting wind energy further up the Severn Estuary.

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