Adiel Batson

Matricultion ID: 28067

Can Offshore Wind Energy Be an Energy Economic Solution to Electricity Generation?

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Energy Economics

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1.0 Introduction

Renewable energy is increasingly taking a larger market share in total energy production of the world year after year. This growth is largely driven by movements to decarbonize the energy sector and become more sustainable in efforts to mitigate climate change. In this bracket of renewable energy, Offshore Wind Energy (OWE) is a fighting solution and option in clean energy generation (Poudineh et al. 2017). The question arises however; on the quest toward greater sustainability, is OWE economically viable a means to produce clean electricity. This report aims to analyse the primary enablers and barriers to OWE. Also in focus is a brief discussion into the possibility of OWE in the coastal waters of Barbados and the general electricity cost implications using a Levelized Cost of Energy (LCOE) analysis conducted by Lazard (2014) in recent years.

1.1 State of the Industry

When it comes to electricity production, wind energy comprised a total share of 6.59% of the entire globe (Ritchie et al., 2022) in 2021. In 2019, the total share of OWE is reported to be just 0.3% of the global production (IEA, 2019). While this represents a small share, it must be considered that OWE is a relatively new technology in comparison to traditional sources used to generate electricity as well as some renewable sources. The overall trend in both onshore and offshore wind energy projects over the last 15 years is a strong increase in capacity and therefore electricity production (Ritchie et al., 2022).

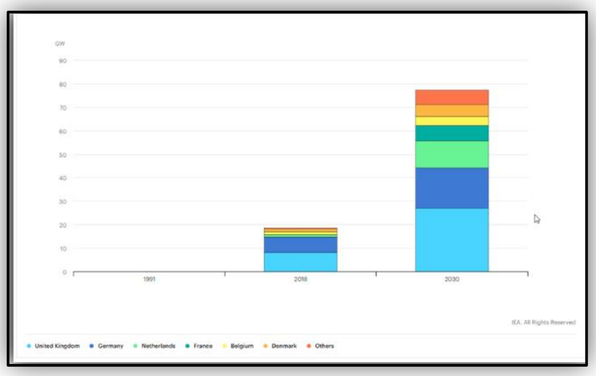

Fig 1.1 – Offshore Wind Capacity, 1991-2030 (IEA, 2019)

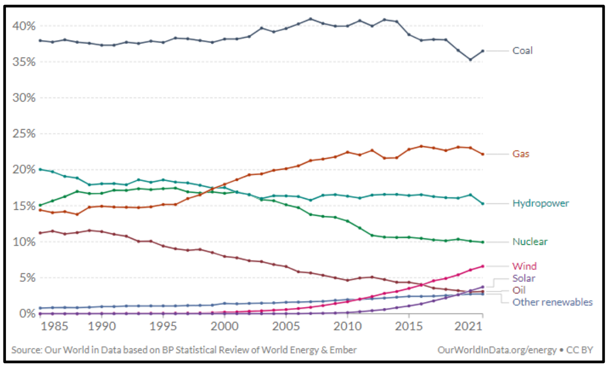

Fig. 1.2 – Share of Global Energy Production by Source from 1985- 2021 (Ritchie et al., 2022).

Looking forward, it appears OW will continue to play a greater role as decarbonisation and sustainability efforts increase (IEA, 2019). The focus then becomes, to what lengths can this technology improve, what are the overall considerations limiting and enabling this technology development and growth of its adoption; how is the economics of it all? For these questions, it is imperative to first understand how the technology works; in a technical sense and on the market. This "market" aspect is driven largely by cost per kWh. A comparison can be drawn to see how cost competitive different electricity generation methods are. Comparisons such as these are usually conducted as LCOE analyses.

LCOEs consider capital costs, fixed costs, variable costs and fuel costs. Averages from these areas are collected from many companies around the world and put together in order to compare different electricity generation technologies (EIPT, 2015). A simplified example of this can be found in Figure 1.3.

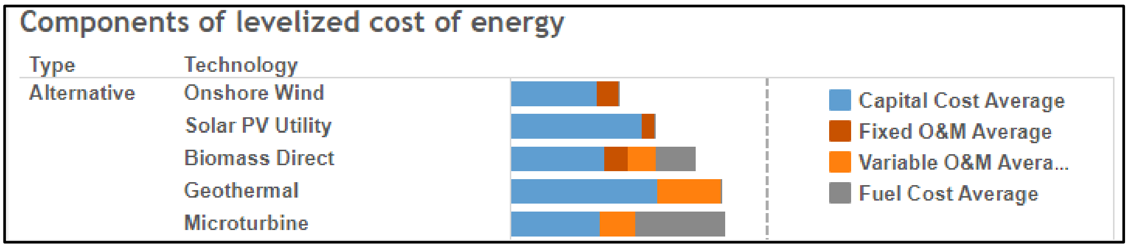

Fig. 1.3 – Example of the Components of LCOE for Different Technology Types (EIPT, 2015).

From Figure 1.3, one can begin to see the fundamental considerations when comparing electricity costs from multiple sources. In this setting, OWE has significant capital at the beginning of the project. On the other hand, not having fuel cost considerations can also be a major advantage. Nonetheless, for a relatively new technology, a challenging position in the industry is to be expected development of OW (EIPT, 2015).

2.0 STATE OF THE TECHNOLOGY

Before breaking down the limitations and potential of OW it is imperative to first understand the functioning of the technology and essential building parameters which then greatly influence aforementioned limitations and potential. That being said, turbines harvest wind energy that derives from differential heating of the earth's varying surfaces during day and night. Indifferential heating across variable surface types and geographies lead to low and high pressure areas, which dictate the

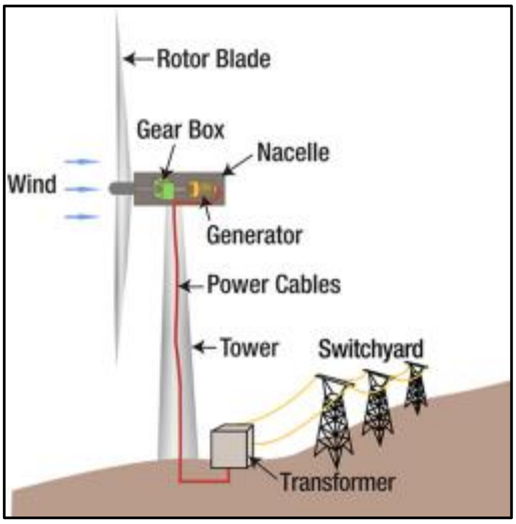

Fig. 2.1 – Components of a Wind Turbine (Kaylani et al. 2021)

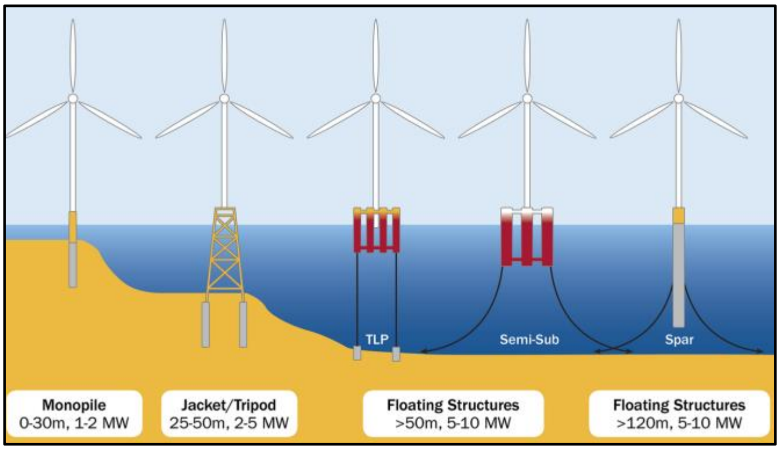

Fig. 2.2 – Foundation Types of OWT (Bailey et al., 2014).

movement of wind across the surface of the earth. The "wind" then moves from areas of low pressure to high pressure. This kinetic energy; movement of the wind, is harvested by wind turbines and turned to electricity (USEIA, 2021).

In principle, offshore and onshore wind turbines work the same. What varies however, is the foundation type, power cable length (variable depending on distance from shore/transformer), and the position of the transformer which may also be at sea (Bailey et al., 2014). These parameters especially have a significant effect on costs and therefore affect the economics of OWE negatively.

The key functioning principle for how much power a wind turbine can generate is given by:

Power [W]= 0.5 x ρ x A x Cp x x Ng x Nb

where,

ρ = Air density in kg/ ,

A = Rotor swept area ( )

Cp = Coefficient of performance

V = wind velocity (m/s)

Ng = generator efficiency

Nb = gear box bearing efficiency

Equation 1 – Power Generation of a Wind Turbine (Sarkar & Behera, 2012).

The theoretical maximum for the efficiency of a wind turbine is 16/27. That means although more power may exist in the wind, the maximum electricity amount convertible will always be limited. In tandem with this, it is important to consider that the wind does not blow all the time, and at a constant speed, and further infrequencies in power produced can be anticipated (Sarkar & Behera, 2012).

Having gained a fundamental understanding into the state of the technology and the state of the industry, more precise questions about the economics of OWE can be explored:

- What are the enabling and limiting factors of OWE?
- Is OWE really an energy economic solution to electricity generation?
- Can OWE be an energy economic solution in the Caribbean island of Barbados?

3.0 Review of Literature & Discussion; Barriers and Enablers of OW

An interesting dilemma arises when analysing the growth of the wind industry with the current barriers and limitations to the technology. Figures 1.1 & 1.2 show a clear increase in the utilisation of OWE but what exactly drives this development?

ENABLERS

On the enabling side, several factors weigh in considerably when planning economic-energy solutions. Offshore Wind Farms (OWF) utilise less land than almost all other energy options. At the first glance, their placement in the sea frees land to be able to be utilised further so the land based ecosystem impact is lower. This is an advantage for OWT when managing the attitude of the society towards them, specifically "Not in my Backyard" (NIMBY) sentiments. With less residential limitations, OWF possesses great potential for utilisation. Since OWF occurs in the sea, the potential to build larger model turbines and larger fleets is greater with less counter tension from societal forces (Poudineh et al., 2017).

Additionally, at sea reduced turbulence of the wind enables a greater potential harvest of wind, and therefore more electricity. Compared to land, more laminar streams of wind occur at sea since its topographical /surface texture is smoother with less obstacles. As a result, capacity factors of OWF compared to their onshore counterparts are higher (IEA, 2020).

Since OWE ultimately occupies space in the water, sufficient attention needs to be placed so that marine environments are not destroyed in the build, use and decommissioning phases of wind turbines (Poudineh et al., 2017). In a study by Bailey et al. (2014), onshore wind turbine impact on land development was 3 times lower than unconventional gas wells, resulting in lower ecosystem costs. Where turbines generally tend to slack however, is in energy production compared to gas wells. Therefore, when analysing the cost per gigajoule produced, turbines generally have a harder time offsetting their ecosystem service costs, although their impact is lower in the first place. When it comes to the ecosystem services impact of OWE, much less research has had time to develop and be published compared to studies done on other technologies. Interestingly however, OWE has the potential to extend and modify benthic ecosystems during their operation phase leading to biodiversity change. This in itself raises some important issues, which obscure the cost-effect to ecosystem services of OWE. Nonetheless, the potential to utilise OWE foundation structures to influence marine biodiversity can forder interesting habitat-research projects, which have the potential to increase biodiversity and coral reef coverage in coastal waters (Causon and Gill, 2018).

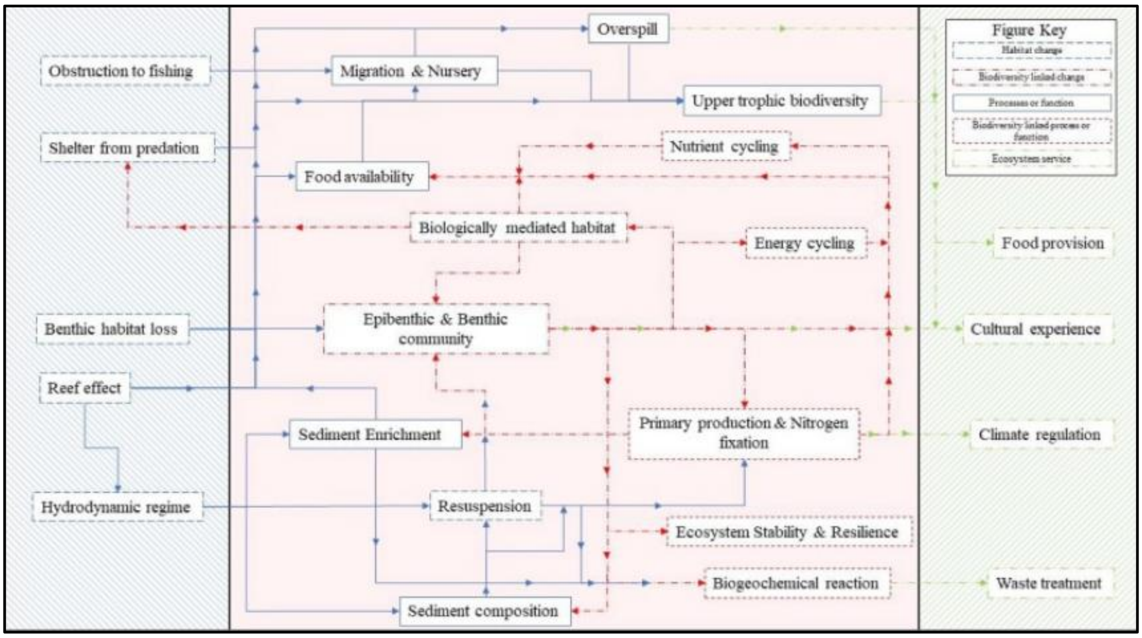

Fig. 3.1 - Biodiversity mediated linkages between habitat modification, ecosystem processes and functions, and the provision of ecosystem services in relation to offshore wind farm structures. Zones represent direct changes (blue hatching – left), secondary changes effecting processes and functions (red – centre), and linked ecosystem services (green hatching – right). Taken from (Causon and Gill, 2018).

The influence that OWE can have on marine habitats is conflicting but potentially positive when combined with a great marine project (Causon and Gill, 2018). OWE farms might help commercially exploited species recover, safeguard migratory populations and juveniles, promote higher trophic biodiversity, and even enable overspill from economically fished populations into nearby fisheries.

This would support human food provision as well as cultural events such as fishing and wildlife enjoyment as seen in Figure 3.1 (Causon and Gill, 2018).

Last but not least, OWE is in a category of its own as the only variable baseload power generation technology. This is due to its capacity factors, which range from 40-50%, rivalling that of efficient gas-fired power plants and coal plants in some regions. This exceeds onshore wind power plants, and almost doubles that of solar PV. Although wind output varies with wind speed, its hourly variability fluctuates minimally compared to other renewable energy sources. For example, 20% from hour to hour, while solar can fluctuate up to 40% between hours (IEA. 2020).

All these factors help cement and forder the increasing share of OW in global energy markets. These factors in tandem with OW's less emissions of GHG during operation and over its life cycle compared to traditional sources (Bailey et al., 2014), help drive the push of the technology to make it an energy economic solution. It is in other words, a powerful tool in deriving energy cleanly to help countries meet their NDCs (Poudineh et al., 2017).

BARRIERS

According to Poudineh et al. (2017), OWE has been historically more expensive than its onshore counterparts have. This is due primarily to the increased risks with building, operating and conducting maintenance in marine environments, which are generally harsher than inland environments.

The first fundamental difference in comparing Barriers to Enablers is that the barriers are directly related to cost factors, technological and procedural inefficiencies. Looking at Figure 3.1, the costs breakdown over the lifecycle of an OWT can be seen.

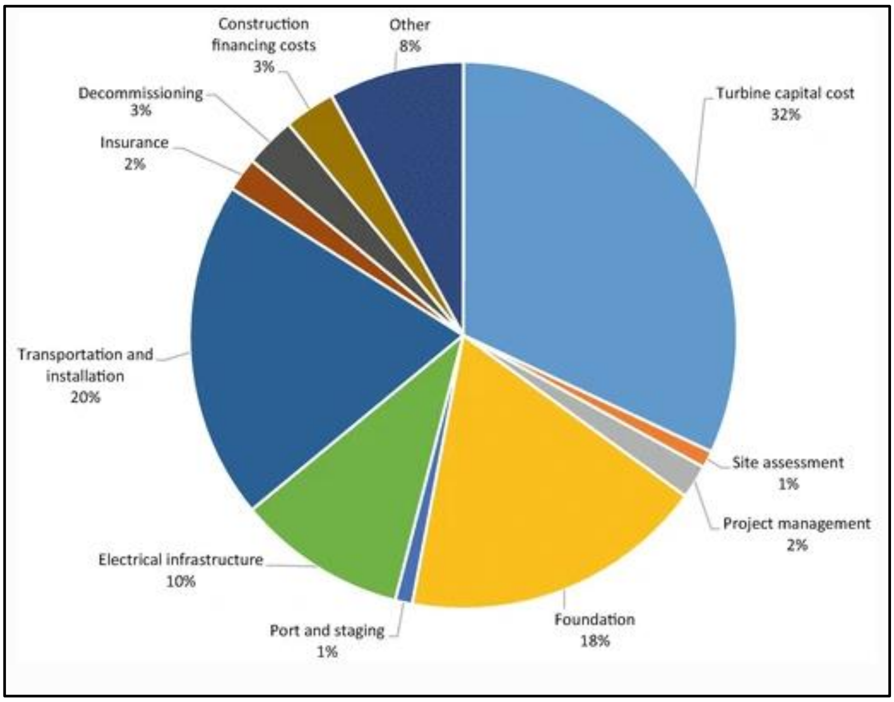

Fig. 3.2 – Cost breakdown During the Life Cycle of an Offshore Wind Farm (Poudineh, 2017).

Turbine capital costs account for the largest costs during turbine life cycle. This cost is largely fixed and forecasted to decrease as the turbine technology develops and economies of scale reduce and streamline manufacturing parts of the turbines (Poudineh et al., 2017). This is also a large cost for onshore wind turbines.

Ignoring turbine capital cost, the largest cost factor comes from transportation and installation of the turbine. In the case of OWE, this is a highly specialised task, often requiring particular ships with specialised equipment, such as cranes and assembling apparatus. In tandem to that, the specialised sea vessels, of which there are not many, can only operate in good weather conditions. Very often, construction processes are postponed for OWE due to strong winds, swells, and rainfall. This further delays the projects, increases risks of the construction process and increases the expense of the overall OWT project (Poudineh et al., 2017).

The third largest cost factor is the construction of the underwater foundation of the OWT. Different arrangements of foundations are used in industry today although one large technological and design hurdle is the combining of the aerodynamic planning of the turbine with the hydroplaning of the turbine foundation. Popular installations are the monopile (see Figure 2.2) although as turbine capacity and therefore size increases, more factors play a role in the foundation type. Also important in foundation design is the distance away from the shore and the depth of water for the installation. Greater distances and depths tend to increase planning complexities and materials which consequently raises costs (Poudineh et al., 2017).

This brings us to the next important consideration, the distance away from the shore. This factor can have multiple implications on the cost factor. For example, the length of subsea cable requires the positioning of the transformer at sea or on the shore, and dictates the ease of accessibility for maintenance operations. Poudineh et al. (2017) reports the greatest operational cost to OWFs is subsea cable reliability. This is noted to mostly be due to inefficient planning and executing of contractors and results in a significant burden of costs during operation (Poudineh et al., 2017).

Other barriers and limitations to OW include intermittency of wind, grid connection cost and responsibility management, and also the ecological impact of the turbines of marine ecosystems and coastal birds. Reported ecological impacts in 2008 include bird and bat collisions; temporary or permanent habitat loss of fish and other marine animals; fragmentation of breeding, feeding, and migratory routes; disturbance of behaviour and stress; and alteration in the plant and animal community composition (OSPAR, 2008). Therefore lobbying environmental groups may have significant influence over the acceptance and undergoing of a farm.

These barriers tend to play a great role in the utility of OWE projects. However, before they can even be implemented, public perception and attitude can have a tremendous influence as well. Citizens tend to worry about the visual impact and the possibility of it affecting their health and well-being. In the past, including public opinion has often extended the time taken for a project to be approved, and is a considerable factor to bear in mind while planning OWE as well (Poudineh et al., 2017).

BRIEF DISCUSSION OF THE POSSIBILITY OF OW IN BARBADOS

Barbados is an independent island nation in the Caribbean Sea. It has a population size of 287,973 people and a yearly consumption of 24,537 kWh (Ritchie et al., 2020). The total consumption is 990 million kWh. Total energy production is 102% the consumption needed; 1 billion kWh.

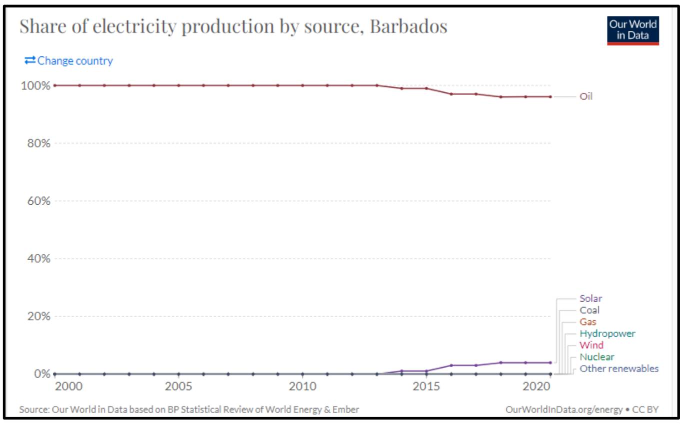

Fig. 3.3 – Share of electricity production by source, Barbados (Ritchie et al., 2020).

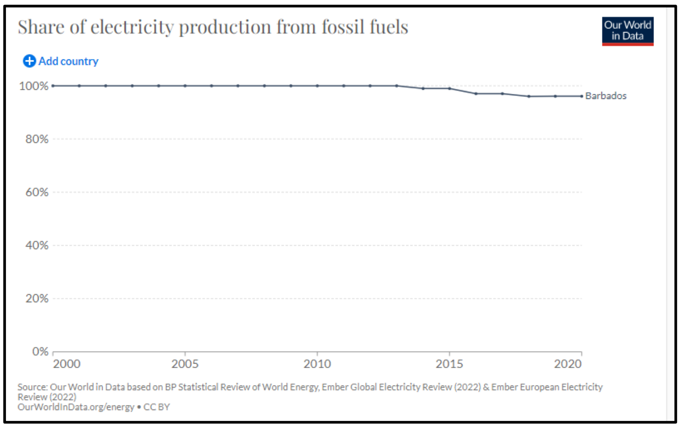

Fig. 3.4 - Share of electricity production from fossil fuel, Barbados (Ritchie et al., 2020).

The island has a total land surface of 439km^2. This can be a challenge when planning on-land wind turbines because although the majority of the population lives around the city centre, the available land surface for wind turbines will still be limited due to close living residences, unsuitable terrain and too much surrounding infrastructure/development. In other words, NIMBY sentiments as well as land space restrictions reduce land-based wind turbine potential. Additionally, since the road infrastructure is so narrow it is not feasible to transport wind turbines within the country (ETI, 2015).

On the contrary, the available water surface is in comparison ripe with potential. The eastern side of the island is exposed to consistent, breezes year round. Advantageously, the eastern side of the island is considerably far less developed than the west, with major activities involving fishing and surfing activities. North Atlantic Trade Winds first arrive across the Atlantic Ocean at this coast as well.

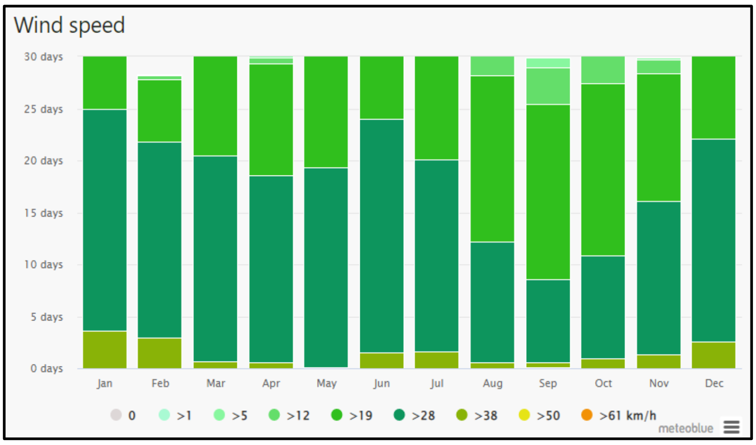

Fig. 3.5 - Aggregated wind speed/hr data over the last 30 years. Barbados (Meteoblue, 2022).

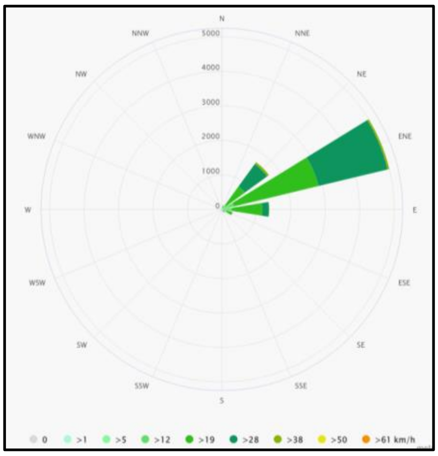

Fig. 3. 6 – Direction of Wind origin, aggregated over last 30 years, Barbados (Meteoblue, 2022).

From 2014-2022 The mean annual wind speed over the year has been 24.62km/h (Weather Spark, 2022). Wind speeds on and around the island are for most of the year favourable; although a slightly higher wind speed may be optimal, the nature in consistency and direction would have strong potential for a wind farm on the eastern side of the island (Weather Spark, 2022).

Currently, the price of electricity in Barbados is USD $0.289/kWh (ETI, 2015). By global standards, this is high; fitting in 4th position in a catalogue from Statista (2021) on household electricity prices worldwide. This exceptionally high cost for such a small country comes from the island's overwhelming dependence on imported fuel for both transportation and electricity generation as seen in Figures 3.3 & 3.4. Barbados produces close to 100% of its electricity using diesel generators. Although this enables a quality supply of electricity with few blackouts over many years, it is extraordinarily expensive to maintain.

Table 1 – Unsubsidized Levelized Cost of Energy Comparison, adapted from Lazard (2014).

Technology	**Price Range ($/MWh)**
Offshore Wind	~ 162
Diesel Generator	297 - 332
Coal	66 – 151
Nuclear	92 – 132
Gas Combined Cycle	61 - 127

Table 1 shows the unsubsidized cost of energy for different electricity generation techniques. The diesel generator was the most expensive alternative per MWh of all generation techniques. By choosing this method, Barbados leaves a great deal of potential open for reducing electricity costs. Even the electricity cost in the island today reflects the range given by Lazard (2014) many years ago; $0.289/kWh or $289/MWh; the lower end of the estimate. Based on numbers from Lazard (2014), offshore wind energy cost $162/MWh or $0.162/kWh, that is almost half the current price. The LCOE therefore puts forward a strong case for the use of OWE in place of/in tandem with diesel generators in Barbados.

Based on the wind profile, the sea to land ratio of the island, the LCOE analysis and historic electricity generation technique using diesel generators in Barbados, OWE has a strong potential to offer cleaner, cheaper electricity than the current system. However, many technical factors still lie in the way before this potential can be realised.

These technical factors and limitations stretch a long list including, integrating OWE into the existing grid, managing the responsibility and managing the running efficiency of the base load demand of electricity. Before OWE can be planned, more research needs to be done to choose the depth for the wind turbines, avoiding coral reefs, receiving public acceptance from the surfing associations, sailing associations and residents utilising and living on this coast of the island. More research needs to be carried out on the appropriate foundation type and the aerodynamic and hydrodynamic feasibility of it all in the changing wave and wind environment present on the eastern side of the island. Finally, the logistics and maintenance methods would also need to be outlined. These factors unfortunately lay outside the scope of this report and are imperative to the question of the economic feasibility of OWE in Barbados. Nonetheless, The island's attitude toward sustainability is commendable, being the world's leader in solar water heating, the possibilities ahead are great and exciting (ETI, 2015). Although many hurdles lay in the way, the possibility and potential of OWE in Barbados would purportedly be of great environmental and economic value.

Conclusion & Bottom Line

Today, OWF is an energy solution, which seems strongly on the way to maturity and further development. At the moment, investment into the technology is heavily reliant on state subsidies to stay afloat (Poudineh et al., 2017). The applicability of OWE is furthermore site specific. For example, the available land to coast area, the industrial energy demand-supply logistics and its distance away from a possible OWE farm play a large role in the cost and therefore feasibility of an OWE farm (Poudineh et al., 2017). Additionally, when considering LCOEs, it is important to remember that definition of costs are narrow; economic externalities are not considered (EIPT, 2015). These include air pollution and climate change impacts. With an "all-encompassing definition" of costs, renewable/low carbon technologies would perform even better than fossil fuels, which at the moment can offer lower electricity prices compared to OWE. Where OWE also competes, is with other renewable technologies such as onshore wind and solar. It then follows, that the existing energy matrix and relating electricity prices of a country have a great role on the competing ability of OWE. As such, subsidies for the OWE industry play a major role in the growth and maturity of the industry.

According to Poudineh et al. (2017), reaching grid parity, phasing out subsidies, mitigating wind power intermittency and improving public perception of OWE are fundamental hurdles which the industry needs to triumph in order to continue developing and expanding in future years. In conclusion, OWE can prove to be an energy economic solution when executed in the fitting environment. As a comparatively newer technology also, its capability continues to be realized.

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