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Combining Wind Power, Aquaculture and Marine Tourism: A novel multi-use blue economy concept for Bangladesh

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ABSTRACT

Multi-use, Blue economy, Wind energy, Aquaculture, Marine Tourism, NPV Bangladesh is blessed with 166,000 sq. km of ocean territory which can be best utilized for sustainable development by innovative implementation of blue economy concept. The country is yet to assess various blue growth concepts within the local EEZ. One such worldwide increasingly popular concept is multi-use blue economy. Literature study shows that any study on viability of multi-use in the local EEZ is almost nonexistent . This paper endeavors to provide a first insight into the concept through a proposed multi-use project for the country. The synergy of three different potential sectors : wind energy, aquaculture and marine tourism have been considered for the project. A concept design is developed keeping in mind physical condition and ecological richness suitable for such multi-use combination. Basic economic analysis is also provided for the proposed project with a sensitivity analysis. The result imply that this project can be an economically viable initiation for multi-use blue economy for Bangladesh and can be a model for promoting the development of new blue economy sectors which often require substantial amount of subsidy especially offshore wind farms. Further aspect of the project where research is required is also highlighted.

1. Introduction.

Multi-use activities can imply different activities constructed upon a single installation, frequently referred to as Multi-Purpose Offshore-Platforms, or they can simply refer to the sharing of the same marine space. The offshore platforms used by the oil and gas industries dating back to the 19th century served as inspiration for the construction of modern floating multi-use platforms and subsea engineering. Many maritime nations are finding themselves in a position to take immediate action to address the problem of the growing competition for space in coastal regions. As a result, there is currently a global drive to identify synergies between marine exploitation businesses and sectors of the Blue Economy in multi-use configurations. Combining many operations into one platform or area helps to reduce infrastructure costs and makes the most of available marine space (Ramos, Díaz and Guedes Soares, 2022).

Following the resolution of the maritime boundary delimitation conflict with Myanmar and India in or around 2014, discussions on the blue economy began in Bangladesh.

Without a doubt, Bangladesh's future development and economic growth will be international trade, the use of marine mineral resources for long-term energy security, the proper management of marine fisheries, and the preservation of the marine environment and biodiversity (Hussain et al., 2018). But so far diversification and growth of new blue economy sectors is rather limited. In this paper we have developed a proposed concept design in the EEZ of Bangladesh and through a preliminary economic analysis endeavored to unravel its relevance and significance there. The key objective of this paper has been to suggest and justify multi-use concept as a solution to the struggle for the new sectors development. Multi-use concept is pioneered and heavily researched in European littoral countries

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many of which have diverse blue economy sectors (Ramos et al., 2022). EEZ of various countries around North Sea are already getting saturated by various marine uses and Marine Spatial Planning (MSP) is getting challenging for the stakeholders (BSH - Maritime Spatial Planning, n.d.).

So, multi-use concept is being adopted there for optimum use of maritime space. Coming back to the case of Bangladesh where most of the blue economy sectors are underdeveloped multi-use concept can be seen as a long-term strategy to reduce competition for space among would be sectors. This paper is only focused to economic feasibility of multi-use project and there by aimed at suggesting it at as a method of new sector development. To achieve that three particular sectors are chosen for synergy : offshore wind farm, marine offshore aquaculture and marine tourism. All three sectors have potential to large scale expansion in the EEZ of Bangladesh .Furthermore, these sectors offer various inherent opportunity for integration and their compatibility is well established by existing multi-use projects (Schultz-Zehden et al., 2018).

2. Concept design.

2.1. Overview.

In this section, we'll discuss about the design that we have conceptualized for this project. The project would be situated six kilometers off Cox's Bazar's shore. In total, 12 bottom-fixed wind turbines would be present, forming a rectangular outline. In between the turbines, four square-shaped mussel culture plots would be installed. From the Cox's Bazar tourist attractions, the location would be conveniently accessible. A multipurpose vessel would be set aside for the project to be used for maintenance of the wind turbines, mussel culture, and sightseeing excursions around the project. For better comprehension, the proposed project's spatial arrangement is fitted into a Google Earth map in Figure 1. The six white dots represent the location of wind turbines and the white squares in between them represent the mussel plots. The corresponding 3D model of the project is presented in Figure 3.

2.2. Location Selection.

Cox's Bazar coastal area seems to be the most suitable for this particular multi-use project for several reasons. Unsurprisingly, synergy of other marine sectors with tourism is feasible close to existing tourism spots(Schultz-Zehden et al., 2018). All of Bangladesh's south-east offshore regions have wind conditions that are favorable for wind farms, with wind speeds averaging 6-7.29 m/s.(Nadi et al., 2019). At the same time, Cox's Bazar coastal region is suitable for mussel culture (perna viridae)(Shahabuddin et al., 2010).The first large scale onshore wind farm is also under construction on the outskirts of Cox's Bazar (Khurushkul Wind Farm - Global Energy Monitor, n.d.). So, stakeholders can benefit from the experience of the current project when considering further wind farm projects in the vicinity of the existing one. All these factors combined make Cox's Bazar the perfect spot for the multi-use project we are conceptualizing in this paper.

Figure 1: Spatial planning of the project off the coast of Cox's Bazar.

Source: Google Earth, 2022.

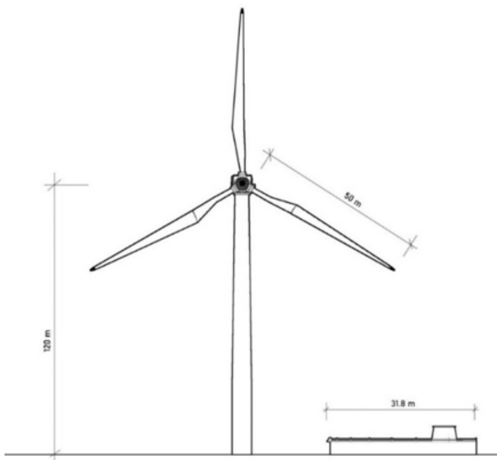
2.3. Wind Farm Design.

Despite the fact that a wind turbine's capacity is typically 5 MW, we chose 3 MW units that are comparable to those in the Khurushkul Project. Because they affect both investment spending and operation and maintenance costs, the distance to shore and sea depth are significant from an economic perspective. As the distance from the shoreline increases, so do the expenses of installation and grid connection. Moreover, the price of foundations rises as water depth does. Though 18.8 kilometers is the typical distance from the coast first farms are frequently found close to the water. The first wind farm in the States, located in Rhode Island, is barely 4.5 km from the coast, while Shanghai DBOWF, China's first offshore wind farm, is just 8–13 km away. Small distances have many benefits, including significantly lower capital and maintenance costs (Díaz and Guedes Soares, 2020). Short distance also facilitate tourism activities like in Rhode island ,USA (Trandafir et al., 2020). Thus, considering all this factors a short distance of 6 km is assumed in this paper. The water depth at the project site is assumed to be 10 m which is the average depth of water within the territorial sea of Bangladesh (Mustafa, 2003). The wind turbine rotor diameter and hub heights are calculated with respect to the selected rated power (Díaz and Guedes Soares, 2020).

2.4. Mussel Culture Design.

Here for simplicity and being similar in context , we adopted the offshore longline mussel culture farm model used in (Buck, Ebeling and Michler-Cieluch, 2010) which was designed for the German North Sea area. V shaped parallel longlines with the capacity for both producing consumption mussel and seed mussel were used . However, we focused only on the consumption

Figure 2: Model wind turbine along with the vessel.



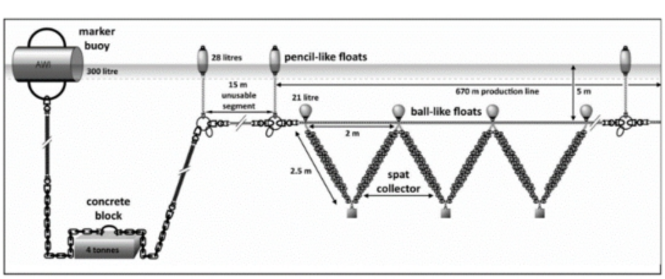
Source: Authors.

Figure 3: Aerial view of the 3D model.

Source: Authors.

size mussel in the concept design . Furthermore, Green mussel is considered here rather than Blue Mussel which is endemic to North Sea region. The key dimensions of the mussel culture longline are kept unchanged and can be seen in Figure 4.

Figure 4: Submerged longline system design with a V-shaped spat.



Source: Buck et al., 2010.

2.5. Tourism Integration.

Synergies of marine tourism with other sectors of this project can be done in several ways specially with the offshore wind farm. Most of the activities is conducting sightseeing trips around the OWFs which is the only one considered in this paper. The boat used for wind farm and mussel culture can be used for the trips and assumed to be equipped with amenities to that end. Figure 5 can give an idea about how the project would appear to the potential tourists from a close distance. All the key dimensions of the concept design are listed in Table 1.

Figure 5: View from the vessel.

Source: Authors.

Table 1: Key dimensions.

Wind turbine		Mussel culture	
Distance from shore	6000 m	Mussel longline length	700 m
Depth	10 m	Spacings between longlines	10 m
Capacity	3 MW	Mussel plot area	49 ha
Turbine number	12	Mussel plot number	4
Turbine hub height	120 m	Total area	196 ha
Rotor diameter	100 m		
Spacing between turbines	1000 m		

Source: Authors.

3. Economic analysis.

3.1. Methodology.

For the purpose of reducing complexity in an economic analysis that is still of a hypothetical nature, we collected data from relevant existing European projects. The cost benefit values of such offshore projects are influenced by myriads of internal and external factors. So, a properly rigorous breakdown of call cost benefit components is required which is beyond the scope of this paper. For simplicity we figured out the bulk cost benefit values related to this projects. The corresponding average values of these components are selected from similar European projects and transferred to the value of 2023. A 2% Inflation rate is used (European Union Inflation Rate - March 2023 Data - 2000-2022 Historical, no date). The currency used in the analysis is US Dollar and an exchange rate of 1€ =1.05$ is used for conversion(Euro to US Dollar Spot Exchange Rates for 2022, no date). Discount rate 12% is used here which is typical for infrastructure projects in Bangladesh (Connectivity et al., 2019). To demonstrate the effect of multi-use NPV value is calculated in three different cases: 1) when only wind farm is operational 2)mussel culture is in multi-use alongside the wind farm 3) when both mussel culture and marine tourism is in multi-use with wind farm. Finally , a sensitivity analysis is outlined with respect to the inherent uncertain parameters of this proposed project.

3.2. Sector specific data sources and assumption.

3.2.1. Wind power.

There is no primary data source available for the capacity factor at our chosen site for this project. However ,one particular study shows that in onshore conditions at Cox's Bazar at the height of 120m capacity factor is 34% (Islam, Rahman and Mannan, 2016).As offshore wind farms tend to have higher capacity factors and due to uncertainty associated with the data, we have taken a conservative value of 35%. The tariff offered by Bangladesh government is 0.12 us$/kwh which at least, we assumed ,would be applicable for any future offshore wind farms (Bangoura, 2008). Life expectancy of the project is taken to be 20 years. Thus, yearly energy production from the 8 wind turbines comes out to be 11036 MWh and yearly revenue is 4.64 m€. Now, the three gross components for wind farm costs are : Initial investment cost, operation and maintenance cost and decommissioning cost. A study of 2016 shows that for wind farm with shore distance 0-10 km and water depth 0-10 m average specific investment cost is 24 m€/MW and 22 m€/MW respectively(Morthorst and Kitzing, 2016). As our concept design satisfy this distance to shore and water depth criteria we chose the value 23 m€/MW. So, the initial investment cost is 82.8 m€ in the context of 2016 which when adjusted by accumulated inflation and exchange rate became 100m$ in 2023. At less than 10 km from shore average wind farm operation and maintenance cost is 24€/MWh.(Work, Jones and Adams, 2020)Similar adjustments leads to a yearly cost of 3.26 m€. And for the decommissioning cost we used a linear regression formula (Gonzalez-Rodriguez, 2017). We got a value of 688 k$ considering the capacity of the project. All the basic data regarding the wind farm segment of the project is illustrated in the Table 2.

3.2.2. Mussel Culture.

As the mussel culture model is adopted from.(Buck, Ebeling and Michler-Cieluch, 2010) For that we had to assume that mussel culture plot installation and maintenance costs in German North Sea will be almost equal to that of Cox's Bazar. So, same data is used for costs and revenue after inflation and exchange rate adjustments. However Green mussel price of 2.75 $/kg had to be used instead of blue mussel .Green mussel price in the local market of Cox's Bazar is around 3 $/kg (Shakil et al., 2019). Due to the inherent uncertainty of the data we assumed a conservative value. Cost benefit breakdown of mussel culture is given in Table 3.

Table 2: Wind turbine cost benefit breakdown.

	Wind turbine	
Cost	Initial investment cost(m$)	100
	Operation and maintenance cost(m$)	3.26
	Decommissioning cost(m$)	6.89
Total cost (m$)		110.15
Revenue	Energy generated (MWh)	110376
	Feed in tariff(US$/kWh)	0.12
	Price(US$/kWh)	0.059
Total revenue (m$)		4.64

Source: Authors.

Table 3: Mussel culture cost benefit breakdown.

	Mussel Culture	
Cost(m$)	Initial investment cost	4.93
	Longlines	0.688
	Collectors	1.647
	Buoyancy	0.11
	Stone/anchors	0.01
	Motor	0.576
	Repair/Maintenance	1.88
Revenue	Biomass per meter of collector(kg)	10
	Biomass per single longline(tons)	16.75
	Biomass per single mussel plot(tons)	11.89
	Market price per kg of mussel(US$)	2.75
Total revenue(m$)		13.1

Source: Authors.

3.2.3. Marine Tourism.

For being a completely hypothetical project it's nearly impossible to precisely predict the number tourist each day will turn out for sightseeing trip. To get a rough value we looked for similar beach area with multi-use of tourism along offshore wind farm already in place. Thorntonbank in Belgium is such a place that has a good match to our concept design. It is still operational and attracts approximately 10,000 people per year for boat tours to local offshore wind farms(Lal et al., 2021). In 2022 ,Belgian sea beaches in the vicinity of Thorntonbank were visited by 1.7 million tourist(Mauricio Ruiz, 2023). Whereas

Cox's Bazar hosted 3 million tourists in the same year(Need for holistic growth of Cox's Bazar, no date). If we assume a linear relation to total turnover of tourists to the number of tourists making trips to the offshore wind farms between both places, 17500 tourist turn over can be expected in the proposed project per year. Now, assuming two trips per day tourist turn out per trip is taken 25 and number of trip per year would be roughly 730. A typical mussel harvesting vessel has around 30m length . Average power and speed are respectively 450 hp and 12 kn. Now for diesel engine typical value of SFC =.40 lb. Per hp and FSW= 7.2 lb. per hp (Calculating Boat Fuel Consumption | Boating Mag, no date). Using the formula fuel consumption (GPH) =(SFC×hp)/FSW extra fuel consumption came out 25 GPH. Considering distance from shore and vessel speed it can be assumed that the vessel engine would be running 1 hr. per trip. So, per trip fuel consumption is approximately 100 L. Assuming diesel price 1 $/Liter extra fuel cost due to tourism per year comes out to be 73 k$. Usually, 5 crew is needed in a trawler of 30 m which we assumed the number of extra crew needed for conducting sightseeing trips. Salary per month offered to fishing trawler crews in Bangladesh ranges from 10,520 tk to 26,000 tk(Tk 10,520 set as minimum wage for fishing trawler workers , no date). So, the average crew wage per year is calculated to be 10 k$. The cost benefit breakdown of the tourism section is listed in Table 4.

Table 4: Tourism cost benefit breakdown.

	Tourism	
Cost	Per trip fuel cost($)	100
	Fuel cost(k$)	70
	Wages(k$)	10
Total cost(k$)		80
Revenue	Per ticket price($)	10
	Yearly trip	730
	Per trip tourist	25
Total revenue(k$)		176

Source: Authors.

4. Result.

As stated in section 3.1 we divided the analysis into three cases. The NPV values are calculated in three additional scenarios under these cases depending on the tariff rate used . The results are outlined in the Table 5 . At the base tariff of 0.12 $/KWh , case 1 is infeasible and case 2 and 3 are feasible with substantial amount of NPV values. The current electricity price in the households of Bangladesh is 0.59 $/KWh. Even at this rate case 2 and 3 remains economically feasible. And only above tariff rate of 0.139 $/KWh case 1 is feasible. So, under the assumptions we made and according to our analysis the proposed multi-use project is quite feasible economically. The positive impact of multi-use is also evident as NPV in case 2 and 3 substantially increased compared to case 1. Result of the sensitivity analysis can be found in Table 6. It is evident that NPV is much less sensitive to trip number compared interest rate, mussel price and capacity factor.

Table 5: Sensitivity Analysis results.

Tariff	0.059 $/KWh	0.12 $/KWh	0.139 $/KWh
Case 1 (NPV)	-65.7 m$	-15.42 m$	0.2 m$
Case 2 (NPV)	8.8 m$	59.1 m$	74.8 m$
Case 3 (NPV)	11.7 m$	62 m$	77.7 m$

Source: Authors.

5. Further research.

This paper is intended to work as a harbinger for multi-use blue economy concept in Bangladesh. Further more rigorous research would be vital for implementing such ambitious projects. A more accurate result could be possible by considering all cost benefit components in the context of Bangladesh which is inexhaustible. Proper sourcing of bathymetry and hydrographic data can enable these efforts. Furthermore, incorporating intangible aspects like environmental and social cost benefit can give a more holistic result. This paper is only focused on the economic analysis of the proposed project. A rigorous technical feasibility along with a comprehensive risk assessment can unravel any hidden limitations of this type of projects.

The NPV can be increased further by considering many other tourism activities triggered by the Artificial Reef effect of offshore wind farms (Pendleton, 2004).

Conclusions

Bangladesh's ocean area is almost the same size as its land area. It goes without saying that it has a lot to gain from the Blue Economy as a maritime nation. The country has taken the lead in advancing the blue economy among the Bay of Bengal's littoral nations. But to take advantage of every potential our EEZ has to offer, Bangladesh should strive for blue economy sector diversification. Furthermore, there is a looming problem of constricted marine special planning which is bound to affect every country as blue economy sees further growth. The multi-use concept can give the much needed impetus to the country's path to a vibrant blue economy. In this paper we presented a novel proposed multi-use project for the country and subjected it to a basic economic analysis . The result imply that this type of multipurpose projects would highly feasible economically . It also signifies that our policy makers can encourage the growth of new blue economy sectors at much less subsidy by embracing the multi-use concept. So, multi-use is surely a topic to be put into further extensive research.

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