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Net Project Value Assessment of Korean Offshore Floating Wind Farm using Y-Wind Semi Platform

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1. Introduction

Offshore winds are one of the most abundant technically available resources of renewable energy. Many countries in Northern Europe, particularly those situated around the North Sea, have been harnessing offshore wind resources for over 40 years and are presently installing wind farms of around 700 MW size with larger ones in planning. European momentum to harness offshore wind is quickly being following by China and Taiwan, and the U.S. has also begun planning for large offshore wind farms. To date, the overwhelming majority of wind farms around the world consist of wind turbines mounted on fixed installations of monopile or jacket type in coastal waters. These fixed farms were initially supported by government by feed in tariffs or guaranteed renewable credits. However, the most recent fixed wind farms in Northern Europe are now being developed and awarded without any government financial incentives or supports.

As available coastal are becoming mush less available, wind energy producers are beginning to consider floating wind farms in deeper waters. There are some benefits of offshore wind farms being located further offshore, wind quality tends to be higher and sight line issues from beach and touristy areas are avoided. The first true floating wind farm of 5 units was installed off Scotland in 2016 approximately 20 km offshore and in 120m water depth. However, while new fixed wind farm installations are being developed to supply power at commercially competitive rates without any government support, the first floating wind farm was developed with large government rate support. This is a consequence of the technical difficulties and costs associated with having to develop a floating wind farm as opposed to a coastal, fixed wind farm.

In order to develop a floating wind farm, the best engineering practices from deepwater oil and gas need to be applied, considering not just platform design, but all aspects of the floating wind farm from procurement and fabrication to offshore campaigns, including operating and maintenance strategies. Once the characteristics of the floating wind farm have been defined, then it becomes necessary to evaluate the potential commercial feasibility (economic feasibility) of the wind farm using the proposed engineering solution.

For this study, a 200 MW floating wind farm located 50 km SE off the coast of Ulsan City is considered. It is assumed that the farm consists of 40 units of Y-Wind semi type floating platform with 5 MW turbine. To determine the economic feasibility of the proposed wind farm, both the Net Present Value (NPV) and Internal Rate of Return (IRR) were calculated. Key NPV and IRR factors are then varied to assess the sensitivity of the NPV and IRR to changes in those factors. The wind farm project is assumed to begin in 2020 and will end in 2043. Key NPV and IRR factors are then varied to assess the sensitivity of the NPV and IRR to changes in those factors. A qualitative assessment of social costs and benefits is also presented.

2. Site and Floating Wind Platform

A wind farm site considered is located at about 50 km SE offshore from the Gori nuclear plant and Ulsan Port, which allows for ready access for connection of the wind farm power to the existing shore grid (Fig. 1). At the site, for a conservative design in terms of platform design and cost, a water depth of 200 m is considered.

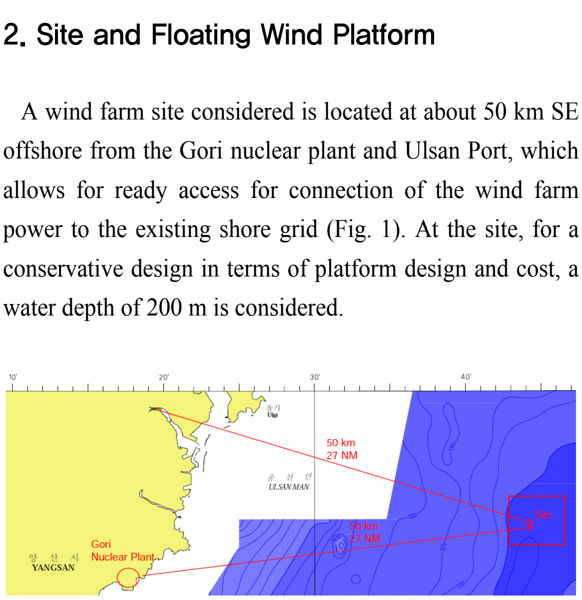

Fig. 1 Floating wind farm site

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For floating wind production platforms, the Y-Wind semi platform has been modified from the existing Y-Wind for US offshore(1-3) for use in this application offshore Korea. Total rated output of the wind farm is 200 MW consisting of 40 floating platforms of 5 MW each. Y-Wind semi platform of 5 MW power production is presented in Fig. 2, where Motion Attenuation Structure (MAS) is not shown.

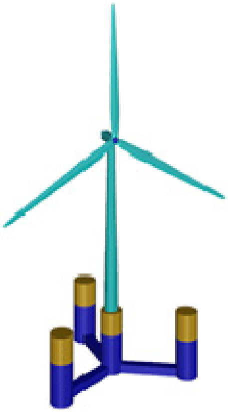

Fig. 2 Y-Wind platform (MAS omitted)

3. Wind Farm Configuration

Spatial separation between each floating platform is assumed to be 10 times the diameter of the turbine blades in both fore and aft and side to side directions. It is assumed that the wind farm is approximately square, with one floating offshore substation located at the downwind side of the wind farm. Inter array power cables connect between the floating platforms and platform to the offshore substation. The offshore substation in turn transfer power to a shore connection by an export power cable. As the exact route of the export power cable is not known, the length of the power cable is assumed to be the distance offshore plus a margin to allow for some route variation. It is also assumed that the inter-array power cables will rest on the seabed, while the export power cable will be buried in a trench all the way from the offshore substation to a shore grid connection assumed to be just beyond the beach.

4. Wind Farm NPV and IRR Inputs

First input into the NPV and IRR calculations is, of course, the capital cost (CAPEX) for the entire wind farm. CAPEX includes all the costs to engineer, procure and fabricate, install and commission for the wind farm offshore. The execution strategy for CAPEX assumes that all components will be procured or fabricated in Korea using Korean fabrication yards and service providers. Even though there is no Korean supplier who currently supplies a 5 MW turbine for offshore operation, there are Korean suppliers for 5 MW wind turbines for shore installations and it is assumed that with some minor adjustments these turbines could be used offshore.

Before any procurement or fabrication of the offshore platforms occurs there is a large set of product development costs associated with such things as development planning, environmental studies, regulatory approvals and site (metocean, seabed and soil) surveys. These pre-construction development costs are also included in the NPV and IRR calculations.

Associated with the development costs are usage fees for occupied space offshore that are assessed for the wind farm occupying air, sea, ocean bottom and export cable route space based on Korean government documents(6-7). Figs. 3 and 4 are extracted from the documents and the same method was used to calculate the occupied areas of mooring, cable and turbine for the present work. These costs, along with onetime fishery compensation fee are also included in the economic analysis.

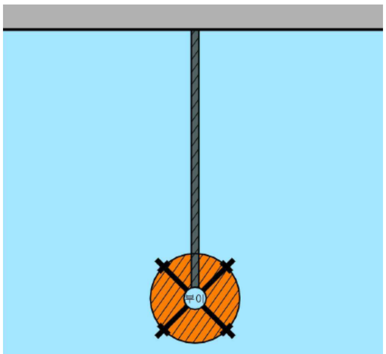

Fig. 3 Occupied seabed area of buoy and export cable(7)

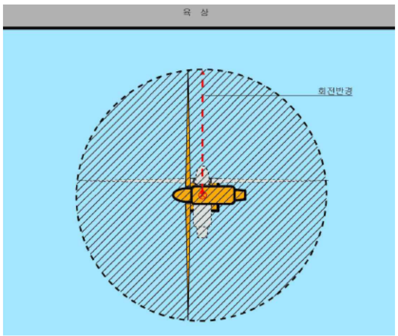

Fig. 4 Occupied area of wind turbine(7)

CAPEX per MW of Y-Wind platform installed can be also found in another work for the 200 MW farm for SE offshore of Korea, where the turbine, foundation, mooring and installations are considered(5).

Considering when the wind farm is installed and operational, operating and maintenance (O&M) costs will arise. For this application, O&M costs are based upon observed values for existing fixed windfarms. As the application is offshore, conservative O&M costs factors are considered.

For power production, a conservative capacity factor and a conservation power export cable transmission loss are also used.

Financial factors such as discount rate, assumed inflation rate are also based upon current or near term projections for Korea. Taxes are not included in the NPV and IRR estimates.

Similarly, the wind farm electricity selling price and Renewable Energy Credits (RECs) selling price are based upon current or near term projections for Korea.

Additional factors considered include 3 years of pre-construction and development costs. Installation of the first 20 Y-Wind semi platforms and the offshore substation and export cable occurs at the beginning of the first year of power production offshore, followed by the next 20 Y-Wind platforms at the beginning of the second year of power production offshore. Production life offshore for each platform is assumed to be 20 years, however, because of the staggered installation, actual wind farm duration offshore is 21 years with production ceasing at the end of the 24th project year.

3.1 Input Factors

In the present study, various cases for NPV and IRR calculation were taken into account, considering the input factor variations. The following inputs given from 1) to 11) are for "Base Case". Table 1 summarizes those key input factors and values. All input values are conservative.

1) Capital cost (CAPEX): 40 floating platforms including turbines, inter-array cables, mooring and anchor costs. One floating offshore substation and one export cable. All engineering, procurement, fabrication, transport and installation costs required to bring the wind farm up to the point of operation are included. The cost of the shore grid connection is, however, not included.
2) Pre-Production and planning phase: 3 years are considered. During this phase, permitting, environmental, site survey and similar activities are undertaken. All costs for such activities are included. One time, public usage (lease) fees are also included during this phase.
3) Production period: Design life of the wind farm is 20 years. During this phase, electrical power and RECs are generated and sold in the markets. Annual public lease fees are included during this phase.
4) Discount rate: 5% in accordance with prior study(4)
5) Capacity factor: 42.5% as per range of values for east offshore of Korea between 24% to 48%(4)
6) Fixed O&M cost: \$15.0/kWyr that is a typical life cycle cost values(4)
7) Variable O&M cost: \$0.025/kWh that is a typical life cycle cost values(4)
8) Wind farm electricity selling price: \$0.064/kWh. SMP electricity price in Korea is about \$0.081/kWh. For this study we assume the wind farm electricity selling price is 80% of the SMP price.
9) REC selling price: \$64.76/REC. For this study we assume the REC price at time of wind farm start will be 80% of the forecast REC price.
10) REC weight: 3.5 based on REC policy published in 2018 in Korea. The REC weight has increased to 3.5 for the farm located at more than 15 km from the shore grid.
11) Cost escalation rate: 2.3%. A small increase over the assumed rate from a previous study(4)

Table 1. Key input factors for NPV and IRR estimates

Factors	Input Values
Capital Cost (CAPEX)	40 floating platforms, with inter-array cables 1 floating substation, 1 export cable
Pre-Production and Planning Phase	3 years
Occupied Area Lease Fees	Annual for occupied space and one time fisheries
Production Period	20 years
Discount Rate	5.0%
Capacity Factor	42.5%
Fixed O&M Cost	\$15.0/kWyr
Variable O&M Cost	\$0.025/kWh
Wind Farm Electricity Selling Price	\$0.064/kWh
REC Selling Price	\$64.76/REC
REC Weight	3.5
Cost Escalation Rate	2.3%

5. NPV and IRR Estimates

5.1 Base Case

For the Base Case the NPV value is approximately $730 millions with a payback period of about 13 years. The IRR value is about 11.8%. Fig. 5 indicates the net yearly expenditure or revenue over the life of the project. Most of expenditures are required in the 3rd and 4th year expenditure in which the wind farm construction and installation occur.

Fig. 6 illustrates the NPV at each year of the project and that the payback period is between 12 to 13 years from project start.

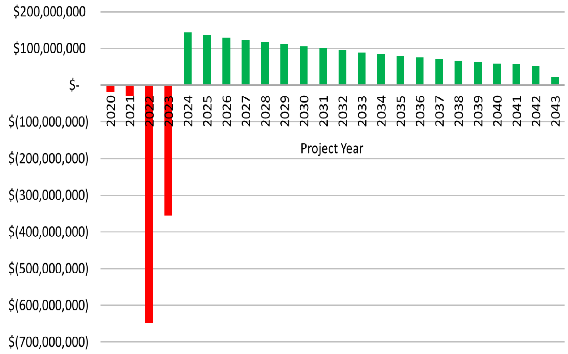

Fig. 5 Net yearly expenditures or revenue

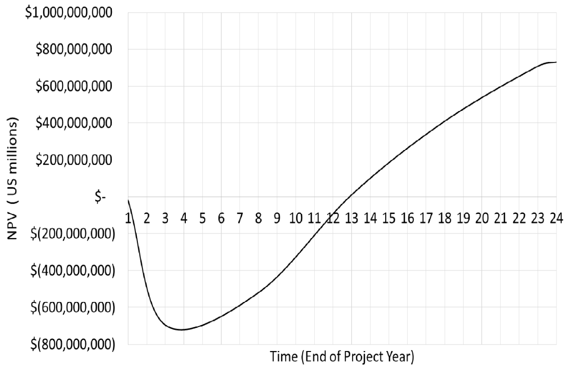

Fig. 6 Change in NPV over the project duration

5.2 Main Components of Revenue and Expenditures

There are only two revenue streams considered for this project, sales of electricity into the power grid and sales of RECs on the secondary market. The majority of the revenue generated over the life of the project will be from the sales of RECs (Fig. 7). Any initiative that increases revenue for either of these factors will benefit the project.

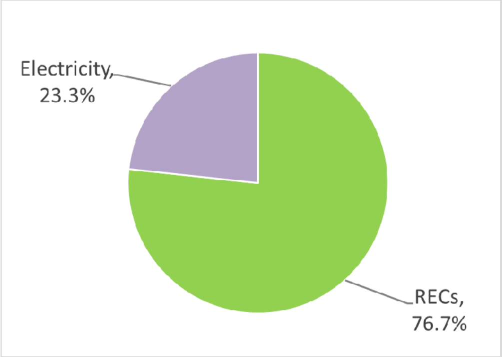

Fig. 7 Proportion of revenue for the project

The majority of the expenditures for the project will be for CAPEX and for O&M. All other expenditures, including Development, Engineering and Public usage fees are around 7% of the total project costs (Fig. 8).

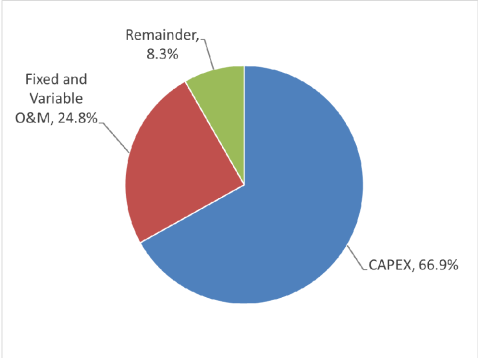

Fig. 8 Proportion of costs for the project

Considering Fig. 8, the largest cost factor is CAPEX, which suggests that the selection of the most efficient design for the wind farm is very important to ensuring the commercial feasibility of the wind farm. O&M costs are also significant and consist almost exclusive of turbine maintenance costs. Therefore, any effort to improve the durability of offshore wind turbines or reduce their maintenance costs will improve the project NPV and IRR.

5.3 Sensitivity of NPV and IRR to Input Variances

In order to ascertain both the most likely range of NPV and IRR values for the wind farm, several input factors given in Table 1 are varied and the calculations are repeated. No variation of REC weight is considered. Table 2 summarizes the effect of proportional variances over individual factors on NPV and IRR values. Table 3 summarizes the effect of increment variances of financial factor on NPR and IRR values.

Table 2. Proportional variances for NPV and IRR factors

Factors	Proportional Variance	NPV Change (millions)	IRR Change
Capital Cost (CAPEX)	+/- 5%	-/+ $51	-/+ 0.7%
Capacity Factor	+/- 2%	+/- $90	+/- 0.8%
Electricity Selling Price	+/- 5%	+/- $25	+/- 0.2%
REC Selling Price	+/- 5%	+/- $25	+/- 0.2%

Table 3. Incremental variances for NPV and IRR factors

Factors	Incremental Variance	NPV Change (millions)	IRR Change
Discount Rate	+/- 0.5%	-/+ $89	~
Cost Escalation Rate	+/- 0.2%	-/+ $9	-/+ 0.1%

As indicated in Table 2, the two proportional variances that have the largest impact on NPV and IRR are CAPEX and Capacity Factor. As was seen in Fig. 8, CAPEX is the largest cost component of the project and again, and this is seen in the NV and IRR sensitivity to changes in CAPEX.

Capacity factor is dependent upon the wind quality at the site. The observed trend in recent offshore wind farms has been that capacity factor is increasing, resulting in more power production and hence revenue. For the Hywind Scotland wind farm, observed seasonal capacity factors have been as high as 65%$^{(8)}$.

5.4 HIGH and LOW Cases

Combination of the individual variances was undertaken in order to obtain a gross overview of their effects. Values in Tables 3 and 4 were again used as inputs for two cases: “LOW Case”, in which all factors are varied to reduce revenue or maximize the costs and “HIGH Case” in which all factors are varied to maximize revenue and reduce the costs. Table 4 summarizes the inputs for both cases and gross NPV and IRR sensitivities.

Table 4. Changes in NPV and IRR for LOW and HIGH Cases

Gross Variance	Factors	NPV Change (millions)	IRR Change
LOW Case	+ CAPEX - Capacity - Electricity Price - REC Price + Discount + Escalation	- $327	- 2.4%
HIGH Case	- CAPEX + Capacity + Electricity Price + REC Price - Discount - Escalation	+ $ 317	+ 1.7%

Fig. 9 compares the difference between the NPV values and payback periods for the LOW and HIGH Cases against the Base Case.

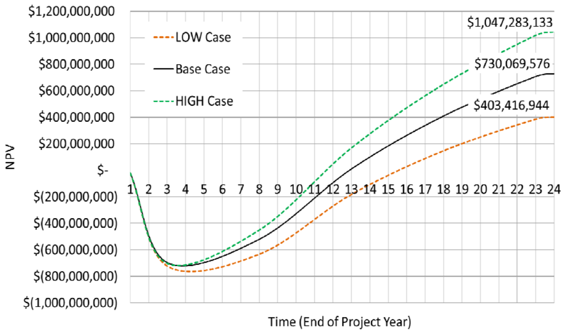

Fig. 9 Comparison of NPV values for LOW, Base and HIGH Cases

As mentioned before, the input factors considered for the “Base Case” are conservative and it is likely better NPV and IRR values with slight shorter payback period can be achieved by better defining the scope of contracts, procurement and fabrication. If project control is weak, then even in the LOW Case, the NPV is still positive and the IRR value of 9.4% is still greater than the assumed discount rate of 5.5% suggesting that the floating wind farm project at the proposed site of 50 km SE offshore of Korea is still feasible.

5.5 Social Costs or Benefits

In addition to just considering technology readiness and commercial or economic feasibility, large projects must also consider the social costs or benefits associated with the project. In this study we do not quantify the social costs or benefits, but we summarize and qualitatively assess what some of those social factors can be.

5.5.1 Social Benefits

The creation of jobs during any major infrastructure project is a large social benefit. Salaries and wages paid through those jobs allow for workers to maintain standards of living and for governments (local and national) to collect taxes which can then be used to pay for various programs.

Another significant social benefit for an offshore wind farm is that there will be no CO_2 emissions during production of power. Production of wind energy is free of fossil fuels.

This leads to another social benefit for those states that are heavily dependent upon the import of fossil fuels: More wind power production means less fossil fuel imports are possible. This enhances energy security and can allow a state to decouple from fossil fuel markets, which can be subject to political manipulation.

For those states willing to develop a floating offshore wind economically, the technology can be exported resulting in additional jobs in the fabrication and supply of wind farm components, jobs in the management and development of wind farms, or even jobs in the financing of such wind farm projects.

5.5.2 Social Costs

Immediate social costs can include impeding upon existing fishing areas and adversely affecting the livelihood of individuals dependent upon fishing activities. Less immediately obvious, but also significant, is that siting of offshore wind farms may adversely affect marine life.

Also if wind farms are located within sight of shore, there will be issues with sight lines that local residents or even tourists may find objectionable. This was a significant concern of the proposed Cape Wind project in Massachusetts of USA when significant local opposition to having fixed wind turbines within sight of shore resulted in the cancellation of the project(9).

6. Conclusion

Using existing technology, it is possible to execute and install a 200 MW floating wind farm with 40 units of 5MW located at 50 km SE offshore of Korea. For the present work, Y-Wind Semi type floating platform were used. This wind farm will be commercially viable producing both electricity and RECs, and for the Base Case considered will achieve a positive NPV of around $730 millions with a corresponding IRR of about 11.8%. Conservative input factors are used for the Base Case, but two other comparative cases indicate that moderate variations in input factors can increase or decrease the project NPV. However, even in the “LOW Case” such as high cost case, the NPV and IRR are still positive and commercially attractive.

Social costs and benefits will next need to be quantified to determine if all parameters for an offshore wind farm project are positive. In this study we undertook a short qualitative assessment of social factors, and it seems that there could be significant social benefits that could more than likely offset any social costs.

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