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Commercially Viable Floating Wind for Offshore Korea

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ABSTRACT

The technology to engineer, fabricate and install floating wind exists and is feasible for all components, turbines or foundations. Applying lessons learned from offshore oil and gas projects with respect to engineering execution options, competitive supply and reduction in life cycle costs makes offshore floating wind a commercially viable energy supply in regions with moderate to high electricity prices or in regions that have other geographical or resource constraints. This paper examines the case for a 200MW wind farm, located about 11km off the south-east coast of Korea at a water depth of 100m, with two different sizes of floating wind turbine units: 3MW and 5MW and considering a Y-Wind semi-submersible configuration for the turbine foundations. The Levelized Cost of Energy (LCoE) is calculated for each configuration and compared against existing electricity prices. The results suggest that a 5MW wind farm with Y-Wind foundations will have an LCoE value of between $0.102 to $0.142/kWh, as compared to an LCoE value of $0.117/kWh for the current Korea residential electricity price. For a 3MW wind farm, the range in LCoE values is $0.114 to $0.154/kWh. For a small premium, offshore floating wind developments can take advantage of local sourced turbines, providing additional economic stimulus to the Korean economy. Additional socio-economic benefits are discussed that can help close any gaps between the LCoE of a floating wind development and other new power generation options. The successful implementation of offshore floating wind is no longer an engineering problem. The challenge is to develop and implement the business plans necessary to achieve the benefits of floating offshore wind energy, namely, diversity of energy supply, access to large amounts of energy where needed, low carbon technology and of course, lower total energy costs.

Keywords : Y-Wind, Floating Wind Turbine, LCoE, Floating Foundation, Wind Farm, Semi-Submersible

1. Introduction

Onshore wind power has emerged as a significant source of clean renewable energy. Onshore wind energy is much more cost effective, in terms of Levelized Cost of Energy (LCoE) than new coal powered thermal generating plants, and in some parts of the world onshore wind energy is already as cost effective, if not more cost effective, than new gas powered (combined cycle) generating plants.

However onshore wind does have some limits. In densely populated areas it is difficult to find locations for wind power installations. There are both spacing concerns affecting generating potential and social concerns including issues such as sight line degradation and low frequency sound (infrasound). Furthermore, while most of the world's population lives along coastlines, on-shore wind power generating areas are generally located farther inland, and may require additional investments in transmission infrastructure. Such is the situation with California, where there are large populations and energy consuming clusters near the coast and separated by large mountain ranges from the prime wind power areas of the American Midwest states such as Texas and Wyoming. Other restrictions for onshore wind power arise in those regions that simply do not have enough available land area for onshore wind. This is the case in densely populated geographically constrained areas such as Korea or the United Kingdom, for islands states such as Japan or the Cayman Islands, or remote out-of-grid areas such as the Indonesian and Polynesian archipelagoes.

Thus, a good solution for wind power generation is to move offshore. This has been the process in Europe where the Northern European states, in particular the United Kingdom have been rapidly pushing wind power offshore. At the beginning of 2017 there was approximately 13GW of offshore wind generation capacity installed in the European North Sea. The vast majority of this capacity is in the form of fixed foundation wind turbines located in shallow waters. However, European power producers have begun to focus on deeper water and the use of floating foundations. Just recently, the Hywind Scotland project, the first true floating wind farm was installed. Although consisting of only five (5) units of 6MW production, Hywind in Scotland is an important step in proving the technology of offshore floating wind.

The problem is to make offshore wind power commercially acceptable. For fixed installations in shallow depth and near onshore grid connections, this has already been achieved. Offshore floating wind costs have, until recently, been too high to be economically attractive for utilities, especially without the benefits of feed-in-tariffs or rate guarantees.

The solution to make offshore floating wind commercially acceptable is the careful application and combination of offshore engineering technology with execution strategy. Additional factors that contribute to the successful implementation of floating offshore wind include local infrastructure capability, proximity to onshore grid connections as well as environmental suitability. The Korean south to south east coast is a very good site for offshore floating wind to be implemented. Incorporating Korean local advantages in combination with well-designed next generation high efficiency floating foundation and improved wind turbine makes floating offshore wind in Korea commercially feasible.

In this study, a 200MW floating wind farm is considered to evaluate the LCoE of the electrical power estimated to be generated by a representative wind farm. The wind farm location is selected about 11km off the south east offshore of Korea. This location has good wind resources, water depths in the ranges of 80m to 100m that is too deep for fixed foundation wind turbines and large grid nodes near the shore crossing that are associated with nuclear plants. Due to the current limitation of local Korean manufacturing to supply wind turbines up to a maximum of 5MW rated capacity, two different size wind turbines of 3MW and 5MW capacity are introduced in the present study. Y-Wind semi-submersible foundations, developed by VL Offshore (VLO) and designed for the two turbine configurations, along with various other appropriate input parameters are used to calculate the LCoE values.

2. Opportunity for Offshore Floating Wind in Korea

A combination of various key factors makes offshore floating wind viable and attractive in Korea. With relatively little onshore land for large farms, no local gas resources as a substitute (i.e., dependence on imported LNG) and high electricity prices, there is opportunity for sustainable and affordable energy from offshore wind. Fig. 1 presents abundant wind resources offshore along the south (including Jeju Island) to south east coast [1]. Fortunately, many of these resources are located in the vicinity of existing high power grid nodes of nuclear power plants as shown in Fig. 2 [2].

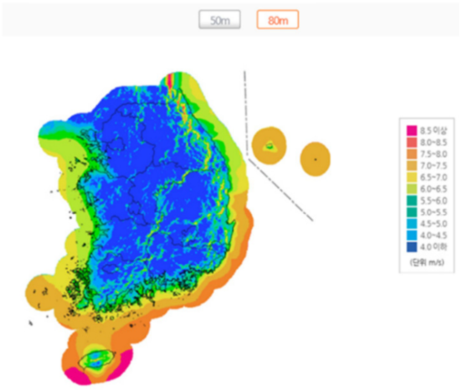

Fig. 1. Wind Resources Offshore Korea

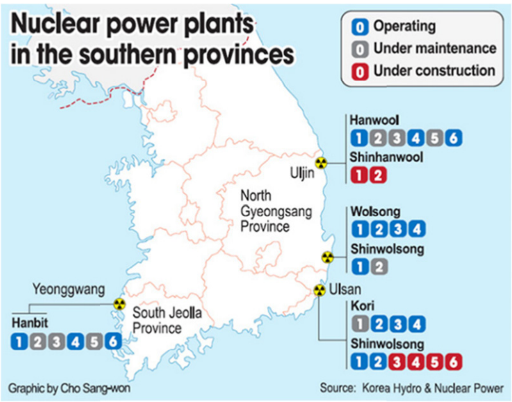

Fig. 2. Location of Nuclear Power Plants

Korea also benefits from having world class infrastructure in terms of offshore platform fabrication capability and a highly educated and well-trained work force. Including other policy factors such as stopping construction of new nuclear power facilities, shutting down and decommissioning existing nuclear power plants and a good faith commitment to Paris Climate Accord carbon reduction goals, Korea is well positioned to implement offshore floating wind power.

3. Types of Floating Wind Foundations

Considerable technology advancements are being made to wind turbines to improve their operability and reliability offshore, while at the same time driving down capital and operating costs. While wind turbine costs are a significant part of the capital and life cycle costs of wind power generation, for offshore installations the foundations (hulls) and mooring costs are the next largest cost components. Thus, to drive down costs for offshore floating wind, foundation and mooring costs also need to be minimized to the extent possible. Foundation cost reductions can be achieved by leveraging offshore floating platform (oil and gas) knowledge and experience to offshore floating wind.

As with traditional offshore energy production three foundation types are most commonly used for floating offshore wind: spar, semi-submersible (semi) and Tension Leg Platform (TLP). These hull forms have advantages and disadvantages and are not used interchangeably in the traditional offshore industry. The same is true for floating offshore wind. Features of each foundation type are summarized in Table 1.

Table 1 Comparison of Foundation Types for Offshore Floating Wind

Floating Foundation Type	Prototype or Concept	Advantages	Disadvantages
Spar	• Hywind	• Hydrodynamic behavior • Relative simplicity of design and construction	• Requires deep water depth for uprighting and integrating tower onto hull • Requires very long yard for hull fabrication • Deepwater mooring can be challenging especially with multiple units in a wind farm
Semi-submersible	• DCNS • Volturn US • Tri-Floater • WindFloat	• Turbine can be integrated quayside (dependent on design and quayside draft)	• Deep tow draft semis may have difficulty finding deep enough quayside for integration of tower on

	• DeepC Wind • Y-Wind Semi • Mitsui	• Proven technology in offshore oil and gas sectors	tower • Requires wide yard for foundation fabrication • Deepwater mooring can be challenging especially with multiple units in a wind farm • If installed and required for operation, the ballast system can be complex and expensive
TLP	• PelaStar • Gicon • Blue H • Y-Wind TLP	• Very good hydrodynamic behavior • Turbine may be integrated quayside if stability is secured	• Anchors can be expensive • Hydrostatic instability before tendon connection • May require specialized installation vessels

The most appropriate type of foundation to use for a planned offshore wind farm development needs to be carefully evaluated and selected.

For instance, for Hywind Scotland, the Hywind Spar foundation and turbines were successfully integrated in sheltered deepwater fjords in Norway, then towed upright as complete units across the North Sea to the operating site offshore Scotland. The integration and tow draft of each Hywind unit is approximately 80m. For areas with access to sheltered deepwater for integration, Hywind is a feasible design.

Off the south to south east coast of Korea, 80 to 100m water depths are only found about 10 km offshore, outside of any sheltered anchorages. Experience from the traditional offshore oil and gas industry indicates that operations offshore are always more risky and expensive than operations nearshore in sheltered waters and much more expensive and risky than operations quayside. Therefore these additional offshore risks and execution costs need to be incorporated into any consideration of using a spar type foundation offshore Korea.

TLP foundations for offshore floating wind can be very efficient but are highly dependent upon anchor types and costs. The traditional offshore industry uses driven piles for anchoring TLPs. Driven piles can be used for offshore floating wind, but these types of piles can be large and expensive to install. Further technology development needs to be completed before TLPs can be considered viable foundations for offshore floating wind.

Semi-submersibles are the most flexible technology today for offshore floating wind and several companies and consortia are rapidly developing such systems. The main advantage of semi-submersible foundations is that they can allow for quayside integration of the turbine and then tow out and installation at site as a complete unit. This quayside flexibility eliminates the need for all but mooring and power cable connections offshore. Furthermore, with a carefully designed disconnectable mooring system the semi-submersible can be brought back quayside to facilitate major maintenance for the turbine. The anchors for a semi-submersible can become complex in difficult sea bottom soil conditions, but they will still most likely be smaller and less expensive than for a TLP pile.

Unfortunately, to date most semi-submersible designs, while incorporating some of the inherent benefits of this technology, still have technology shortcomings in other areas that are proving significant barriers to the commercialization of their design. Deep drafts during turbine tower lift and integration or during tow out or tow back prevent some semi designs from being accessible to all but the largest and deepest ports and drydocks. Semis with the turbine installed off the platform center require deeper drafts than a symmetrical system and may require an active ballast compensation system to maintain verticality of the turbines during operations. Finally, some semi designs have complex structural framing systems and appendages that increase fabrication cost and do not allow for ease of construction in a series.

4. Factors Affecting Wind Farm and Offshore Floating Wind Design

In addition to foundation type selection, there are several other factors that affect wind farm design and design of individual offshore floating wind units. These additional factors can be divided into three broad groups: field factors, foundation factors and execution factors.

4.1 Field Factors

Field factors include geographical, hydrographical and infrastructure factors that affect the total wind farm development. These include the metocean conditions at the site, such as wind, wave and currents, water depth, soil conditions for anchoring, and availability of infrastructure such as offshore vessels for construction, installation and support activities.

Electrical system factors, including number and location of substations and layout of the export cable, including distance to the onshore grid connection, will affect the productivity and cost of the wind farm.

Commercial factors such as turbine size to be used and supply chain issues should also be considered as field factors. For example, while larger turbines sizes are being touted as the best way to reduce offshore floating wind costs, there are only two or three suppliers worldwide that currently supply the largest, marinized 8MW+ sized turbines. In contrast there are many suppliers globally and local to Korea that can supply turbines for offshore in the lower, yet still substantial, power ratings from 3MW to 7MW. Commercial competition on turbine supply can have a beneficial impact on overall wind farm initial cost and life-cycle costs.

4.2 Foundation Factors

Foundation factors include the effects of field factors such as metocean conditions as well as local infrastructure support during fabrication. Metocean conditions will drive foundation dynamic response and design. Turbine tolerances to foundation dynamics need to be considered. In addition, hydrostatic stability during all modes of integration, wet tow and installation of the foundation need to be evaluated. Requiring the use of temporary buoyancy modules in order to remove a foundation from a drydock or to maintain stability during a transit condition will add complexity and cost to the foundation design.

For fabrication of the foundation, the availability and characteristics of fabrication yards near the installation site will need to be considered. Characteristics of the fabrication yard include quayside draft, air draft and crane lift limits. Crane lift limits also need to be considered for the turbine. Even the structural framing system used on the foundation has an effect on cost: In general stiffened structure framing is less expensive to fabricate than mixed framing systems using stiffened panel and tubulars. In addition, for round column semi-submersibles, the fabrication yard ability to roll columns needs to be incorporated into the design. This may not be an issue with Korean fabrication yards, but can be an issue with fabrication yards in other parts of the world.

As opposed to the traditional offshore energy industry where most foundations are one-off design, offshore wind farms consist of multiple, identical designs. A simple structural design that is easy to build in a series manner is most cost effective.

4.3 Execution Factors

Execution factors are also very important in reducing floating offshore wind costs to within commercially acceptable values. As previously mentioned, turbine installation and integration quayside or in a drydock, is much less risky and costly than the same activities executed near shore or farther offshore.

Finally, life cycle costs arising from major maintenance or repairs need to be considered at the design stage. Offshore locations expose the foundations and turbines to a highly corrosive environment and dynamic loads not experienced by onshore turbines. Furthermore extreme weather events create the risk of a major failure of the turbine. In order to repair the turbine, either a turbine lift and transport vessel needs to be dispatched offshore, or the foundation needs to be disconnected from its mooring and towed to port for quayside repairs. Again, operations offshore are always more risky and costly than operations quayside.

4.4 VLO Y-Wind Semi-Submersible Foundation

Examining the state of existing semi-submersible foundation designs, VLO identified several key improvements in design and technology that will make semi-submersibles cost effective for offshore floating wind:

a) Reduction of dynamic responses of the foundation

b) Shallow draft during tower and turbine lift and integration, in order to be accessible to as many ports, fabrication yards and drydocks possible

c) Hydrostatic stability during all conditions including transit and in-place

d) Using non-special vessels of opportunity for towing and installation operations

e) Simple, braceless structural design to allow for low cost and fast series production

f) No active ballasting for operations

g) Detachable mooring to allow for disconnect and tow back to port to facilitate quayside major maintenance and repair of the turbine

Incorporating these technology factors, VLO has developed the Y-Wind semi-submersible foundation as depicted in Fig. 3. These design features are in response to many of the design objectives identified by the NREL as necessary to reduce offshore floating wind costs as described in Section 7.3 of [3]. Though the NREL report focused on U.S. offshore wind energy, VLO applied the strategy to a design which can then be used globally.

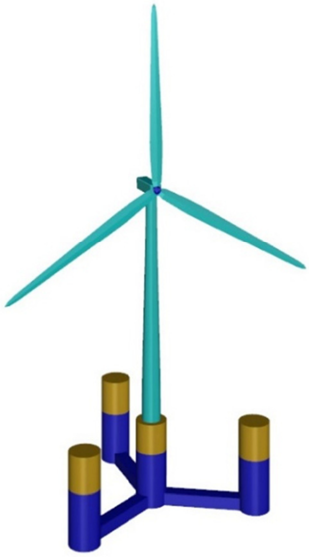

Fig. 3. Y-Wind Semi Configuration with Turbine on Center Column

The VLO Y-Wind semisubmersible foundation is engineered to be the most efficient foundation possible with excellent stability and dynamic performance with motion dampening structures. It is designed for ease of fabrication and simplicity of operation in order to minimize capital and operating costs to the greatest extent possible. In addition, the mooring system is designed to be detachable to allow for quayside major maintenance or repair of the turbine system.

5. Parameters of LCoE Estimate for a Wind Farm off South East Coast

For evaluation purposes, the Y-Wind foundation is used for a hypothetical wind farm offshore South East of Korea. The following parameters summarized in Table 2 are used for evaluation for two floating power units, with 3MW and 5MW turbines installed. The wind turbine particulars for the 3MW and 5MW designs are based on the data in references [4] and [5], respectively. Detailed design and analysis results of the 5MW unit can be found in the references [6] and [7].

Table 2 Design Parameters for Offshore Korea Floating Wind Farm with Y-Wind Semi

	3 MW Y-Wind	5 MW Y-Wind
Displacement, in Service	4,300 tonnes	7,770 tonnes
Wind Farm Power Required	200 MW	200 MW
Number of Units	67	40
Distance offshore	11 km	11 km
Water depth	100 m	100 m
Number of substations offshore	1	1
Number of export cables and shore grid connections	1	1
Metocean conditions	Rated and Cut-out wind, extreme and survival as per ABS design requirements [8]	Rated and Cut-out wind, extreme and survival as per ABS design requirements [8]

Wind Farm arrangement offshore is in a radial orientation with respect to the substation. Typical layout and prevailing wind direction for each type of wind farm are shown in Fig. 4 and Fig. 5. Spacing between the Turbines is a factor of turbine blade diameter (D). For this study, spacing is about 6 D laterally, and 8 D for turbines downstream, which is consistent in terms of density to the mean array density of 19 operating offshore wind power projects in Europe [3]. Approximately 37 km^2 and 50 km^2 are required for the 3MW and 5MW wind farm, respectively.

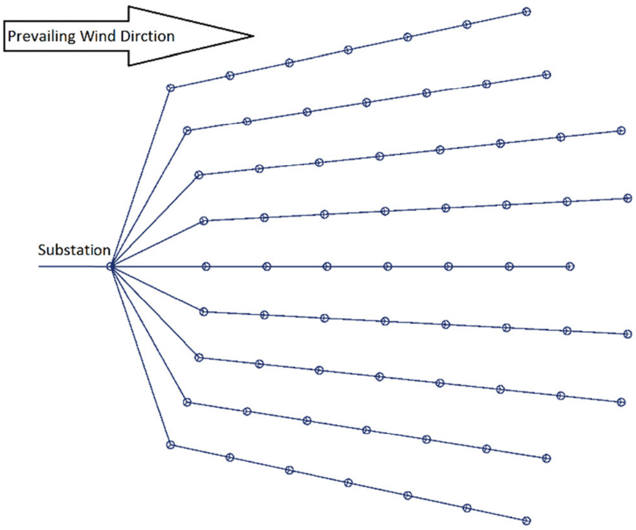

Fig. 4. Floating Wind Farm Layout for 3MW Turbines

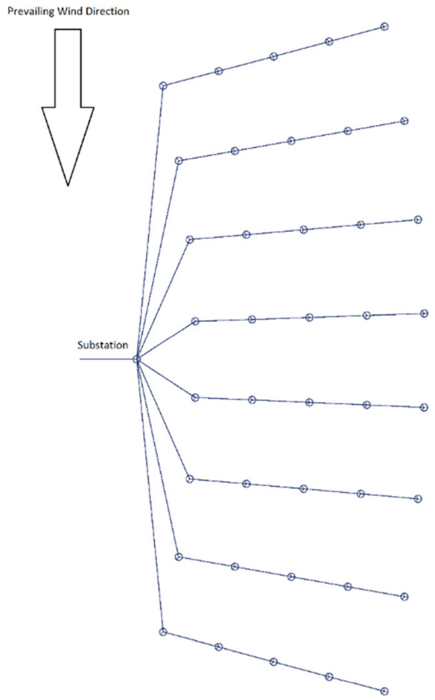

Fig. 5. Floating Wind Farm Layout for 5MW Turbines

Common factors for LCoE calculation are summarized in Table 3. The LCoE of the electricity generated by the wind farm is calculated using the United States Department of Energy, NREL on-line LCoE calculator [9].

Table 3 LCoE Calculation Input Factors

	Input	Basis
Capital Cost	For each hull	Y-Wind cost components using NREL unit costs [3] (Note 2)
Period	25 years	Typical value for current generation of turbines
Discount Rates	3.0%	Assuming Korea is similar to US Federal [9]
Capacity Factor	42.4%	As per range of values for east offshore of Korea between 24% to 48% [10]
Fixed O&M Cost	$15.00/kWyr	Typical Life Cycle Cost Values [11]
Variable O&M Cost	$0.025/kWh	
Electricity Price	$0.093/kWh (Note 1)	Korea Residential Gross Domestic Product (GDP) Based [12]
Cost Escalation Rate	2%	Average rate of inflation, Korea, past year [13]

Note:
1. A Series of Residential Prices are input and compared to the LCoE of the renewable energy system
2. Construction learning curve improvements and bulk procurement factors are considered

The LCoE is calculated in two:

- Case I Y-Wind Units: The units include the wind turbines, floating foundation fabrication, tow and installation, mooring and in-field power cables, and O&M.

- Case II Y-Wind Units with Field Components: The substation, export power cable, shore grid connection and field component O&M are added to the Y-Wind units

6. Results and Discussion

The LCoE calculation results the 200MW floating wind farm are plotted for the Y-Wind units and the Y-Wind units with the field components in Fig. 6 and Fig. 7, respectively.

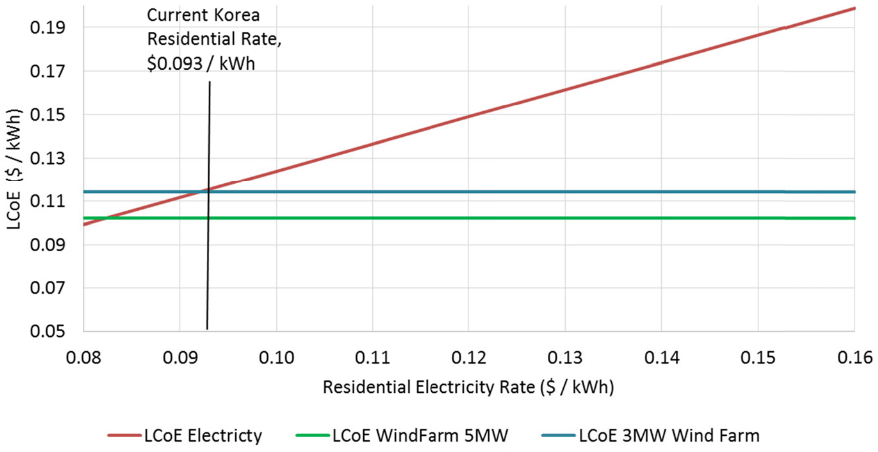

Fig. 6. LCoE vs. Residential Electricity Prices for Y-Wind Units (Case I)

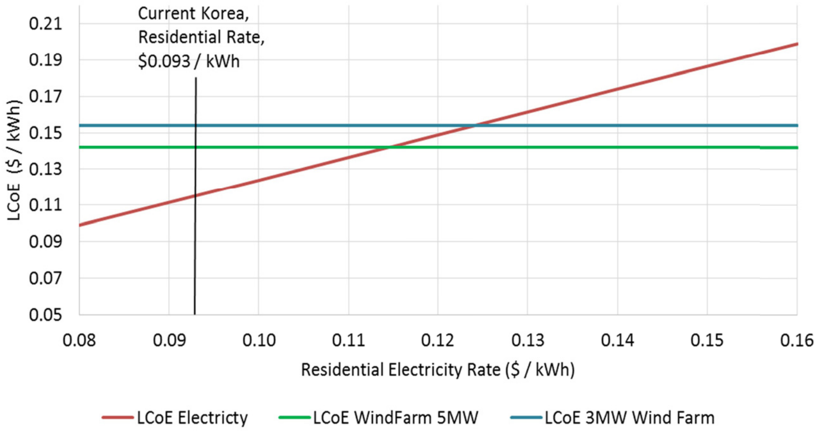

Fig. 7. LCoE vs. Residential Electricity Prices for Y-Wind Units with Field Components (Case II)

Table 4 summarizes the LCoE values for Case I for the threshold electricity prices for 5MW and 3MW wind farm, and the current Korean residential electricity price. The intersection of the indicated electricity price in Table 4 with the LCoE curves of Fig.6 is the LCoE value.

The LCoE of the 5MW floating offshore wind farm will be lower than the LCoE of any residential electricity price that is greater than about $0.083/kWh and the LCoE of the 3MW wind farm will be lower than the LCoE of any residential electrical price that is greater than $0.091/kWh. These are the threshold electricity prices above which floating offshore wind begins to be commercially feasible in Korea.

Table 4 LCoE Values for Y-Wind Units (Case I)

Residential Electricity Price ($/kWh)		LCoE ($/kWh)		
	Value	Electricity	5MW Wind Farm	3MW Wind Farm
5MW Wind Farm Threshold Price	0.083	0.104	0.102	0.114
3MW Wind Farm Threshold Price	0.091	0.115	0.102	0.114
Current Korea Residential Price	0.093	0.117	0.102	0.114

Table 5 summarizes the LCoE values for Case II with the field components included. The field component costs add approximately $0.04/kWh to the LCoE values for both wind farm configurations. This additional field cost increases the commercially viable wind farm LCoE threshold electricity price to above $0.114/kWh for the 5MW wind farm and above $0.123/kWh for the 3MW wind farm. While these threshold prices would be commercially acceptable for much of the floating wind in Europe or US, these prices and associated LCoE values suggest that additional engineering analysis and design needs to be undertaken to optimize and reduce field component costs as much as possible. While several initiatives have reduced the floating wind turbine, foundations, mooring, etc., costs, similar results still need to be achieved with the field components such as substation and export power cables.

Table 5 LCoE Values for Y-Wind Units with Field Components (Case II)

Residential Electricity Price ($/kWh)		LCoE ($/kWh)		
	Value	Electricity	5MW Wind Farm	3MW Wind Farm
5MW Wind Farm Threshold Price	0.114	0.143	0.142	0.154
3MW Wind Farm Threshold Price	0.123	0.155	0.142	0.154
Current Korea Residential Price	0.093	0.117	0.142	0.154

It should be noted that advances in turbine and blade technologies are resulting in incremental increases in power output or efficiency improvements. For example, for this study we used a turbine with a fixed 5MW output rating based upon NREL model properties [11]. However, discussions with several turbine suppliers suggest that turbines of the same size and dimension as the 5MW unit assumed for this study can be obtained with slightly higher ratings, between 5.3 to 5.5MW or with better capacity factors. Such uprated but same size turbine units will reduce the 5MW wind farm LCoE values. Similar reductions for the LCoE values for the 3MW turbine units can also be achieved with incremental improvements to the turbine efficiency without increasing the turbine size.

Other initiatives advocate going with larger and larger turbines as the best solution to driving LCoE costs to below current electricity prices. While this is a valid approach, it may not be an optimum approach. Considering the 200MW wind farm example in this study, choosing a 6MW turbine design instead a 5MW turbine design may reduce the LCoE of the individual units. But it may also increase the LCoE of other in-field power components and O&M costs. Larger turbines units with larger blade diameters increase the spacing between the units in the field, and, thus, while there may be fewer in-field power cables, the total length and cost of those in-field components could actually increase. Furthermore, the supply of very large offshore turbines is limited to only a few non-Korean firms and these turbines will either need to be imported into Korea or significant investment in infrastructure investments will need to be completed in Korea in order to facilitate the use of such large offshore turbines in Korea. In addition, larger floating offshore foundations may limit fabrication to only the largest fabrication yards with the deepest quayside drafts and largest drydocks and lifting cranes. It is not an automatic answer to use ever larger turbines offshore to reduce the LCoE of offshore floating wind.

Another area that could help reduce LCoE values for the wind farm again relates to the arrangement of the individual units within the wind farm. Separation of the units is currently driven by empirical guidelines. If ongoing research can optimize the spacing to minimize down turbine wake effects, thus increasing the capacity factor, or can reduce turbine spacing in order to decrease in-field cables lengths, LCoE values can be further reduced.

Although the current work is based on an offshore floating wind farm Korean offshore, it is interesting to compare results with the NREL projection of LCoE for offshore wind [3]. Fig. 8 superimposes the calculated LCoE for Y-Wind presented herein on the NREL plot, assuming the 5MW turbine farm development commences in 2018 and achieves a commercial operation date (COD) in 2022. The data point is very close to the NREL Cost Reduction Pathway for that year. The Y-Wind concept with its improvements over other semi-submersible concepts aligns with the vision for offshore wind.

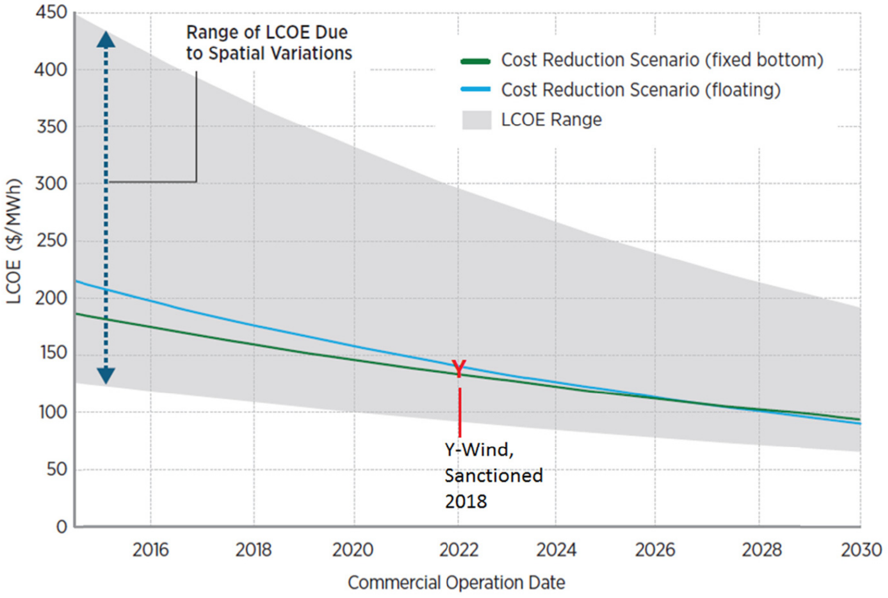

Fig. 8. LCoE (Unsubsidized) of US Wind by NREL (Figure ES-3, [3]) vs. LCoE of Y-Wind Semi for Korea Offshore

The above discussion is solely focused on the cost of offshore floating wind installations and how to make them commercially viable in today's socio-economic climate. However, a number of fundamental considerations beyond pure cost are worth considering in any decision process regarding an investment in a new energy source:

a) Carbon dioxide emissions that contribute to climate change. Although emissions from electrical generating facilities that burn fossil fuel contribute a significant fraction of the man-made carbon dioxide emissions to the atmosphere, the cost of mitigating any climate induced impacts is borne indirectly by consumers of electrical power rather than producers. A carbon tax on electrical generation in the range of $20-$50/tonne carbon dioxide (as is being considered in many regions) would make this cost more transparent and increase the cost of electricity from fossil fuel sources by several cents per kWh.

b) Health impact from air emissions. Atmospheric emissions from the burning of coal to generate electricity have been shown to impact people's health and can be linked statistically to mortality rates. This creates a burden on healthcare systems and leads to shortened lifespans, both of which impact a country's economic potential.

c) Local jobs. A change from burning fossil fuels for generating electricity to renewable sources shifts expenditures on procurement of fuel to procurement of equipment. For a country like South Korea, fuel must be imported while the workforce to build equipment is national.

d) Balance of trade. Since Korea has few fossil fuel resources, these must be imported. By saving the cost of fuel, Korea will have more money available to purchase other international goods and products.

e) National security. Energy independence has been a key component of national security throughout history. Shifting from external sources of fuel to locally generated power reduces dependence on other countries, some of whom may be potential adversaries in future global conflicts.

All of the above factors add value to renewable resources such as offshore wind. One can easily justify a deficit of several cents per kilowatt-hour on a pure cost basis.

7. Summary and Recommendations

For an estimate of LCoE of the floating offshore of Korea, a wind farm of 200MW capacity located about 11km off the southeast offshore of Korea was considered. The farm was assumed configured with two different Y-Wind semi-submersible foundations designed for 3MW and 5MW turbines. The wind farm design life considered is 25 years. The LCoE values calculated for those configurations are compared against the LCoEs of a range of electricity prices, including the Korea residential electricity price. The results suggest that a 5MW wind farm with Y-Wind foundations will have an LCoE value of between $0.102 to $0.142/kWh, as compared to an LCoE value of $0.117/kWh for the current Korea residential electricity price. For a 3MW wind farm, the range in LCoE values is $0.114/kWh to $0.154/kWh. The 5MW floating wind farm shows lower LCoE than the 3MW floating wind farm. It is seen that the offshore floating wind units with 5MW rating and including substation, export system and shore connections, can be implemented cost effectively where market electricity prices are greater than $0.114/kWh. For the 3MW wind farm, the threshold electricity price is $0.123/kWh.

The floating wind farm LCoE can vary depending on several other factors such as total capacity of the wind farm, design life of the foundation, site and metocean conditions, wind farm layout and infrastructure. As such, further detail analysis of the LCoE for the specific site of the wind farm for Korean offshore is recommended.

Offshore floating wind energy is commercially acceptable in areas with moderate to high electricity prices and in areas that have other geographical or resource constraints to bringing additional energy supply on-line. Using high efficiency floating foundations and mooring technology along with competitive supply, robust execution engineering and a competitive supply and manufacturing strategy can drive the offshore wind farm LCoE below current electricity prices. Additional offshore wind farm cost reductions for the export cable, substation and shore grid connection will help reduce wind costs even further. Additional research into optimizing wind farm arrangements and layouts could realize increases in power production and additional reductions in the in-field costs. Finally, consideration of additional socio-economic impacts as part of the decision making process will close the apparent cost gap between current market prices for electricity and floating offshore wind investments.

The technology for offshore floating wind has advanced sufficiently that using high efficiency foundation designs, low cost mooring and series production results in commercially viable development opportunities. In addition, in certain areas, including offshore Korea, it may no longer be necessary to design for and implement the largest turbines available in order to achieve economies of scale to make offshore floating wind viable. The successful implementation of offshore floating wind is no longer just a fabrication yard activity, it is a manufacturing process requiring all factors to be optimized to the extent possible.

References

[1] http://www.greenmap.go.kr/02_data/data01.do#2#1#1

[2] http://www.koreatimes.co.kr/www/news/biz/2016/09/123_214494.html

[3] Beiter, P., Musial, W., Smith, A., Kilcher, L., Damiani, R., Maness, M., Sirnivas, S., Stehly, T., Gevorgian, V., Mooney, M. and Scott, G., 2016, “A Spatial Economic Cost Reduction Pathway Analysis for US Offshore Wind Energy Development from 2015 – 2030.” NREL 66579

[4] Jonkman, J., Butterfield, S., Musial, W., and Scott, G., 2009, “Definition of a 5-MW Reference Wind Turbine for Offshore System Development”, Technical Report, NREL/TP-500-38060

[5] Boo, S.Y., Kim, K.-W., Lee, K., Park, S.W., Choi, J.-Su. and Hong, K., 2016, “Design Challenges of a Hybrid Platform with Multiple Wind Turbine and Wave Energy Converters”, Proc. of 21st Offshore Symposium, SNAME, Houston, Texas

[6] Boo, S.Y., Shelley, S.A. and Kim, D., 2017, “Design and Dynamic Performances of Y-Wind Floating Offshore Wind Turbine Platform”, Proc. 27th ISOPE Conference, San Francisco, California.

[7] Boo, S.Y., Shelley, S.A. and Kim, D., 2017, “Dynamic Performance Analysis of a New Semi Type Floating Offshore Wind Turbine Platform”, Proc. 22nd Offshore Symposium, SNAME, Houston, Texas

[8] ABS (2015), Guide for Building and Classing – Floating Offshore Wind Turbine Installations

[9] https://www.nrel.gov/analysis/tech_lcoe.html

[10] Oh, K.-Y., Kim, J., Lee, J. and Ryu, K., 2012, “Wind Resource Assessment around Korean Peninsual for Feasibility Study on 100 MW Class Offshore Wind Farm” Renewable Energy 42

[11] Myhr, A., Bjorkseter, C., Agotnes, A. and Nygaard, T.A., 2014, “Levelized Cost of Energy of Floating Offshore Wind in a Life Cycle Cost Perspective”. Renewable Energy 66

[12] http://www.yonhapnews.co.kr/economy/2013/11/19/0302000000AKR20131119164000003.HTML

[13] http://www.inflation.eu/inflation-rates/south-korea/historic-inflation/cpi-inflation-south-korea-2017.aspx