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Communication

Is Zero Subsidy in Fixed-Bottom Offshore Wind Farms Feasible? The Case of Incheon, South Korea

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Abstract: It has been stated that by 2030, South Korea will have increased their capacity for wind power from 124 MW to 12 GW. According to official statements, offshore wind turbines will provide most of this wind energy. In order to determine the costs for an offshore wind energy production site, an economic analysis was performed in Incheon, South Korea, and the levelized cost of energy (LCoE) value was calculated at 129.97 USD per MWh, and the net present value and the internal rate of return were also calculated. Various scenarios were tested, and it was proven that minimum or no governmental support can lead to economically problematic projects. Is zero subsidy the future of the offshore wind industry?

Keywords: offshore; wind energy; zero subsidy; LCoE

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Citation: Lee, J.; Xydis, G. Is Zero Subsidy in Fixed-Bottom Offshore Wind Farms Feasible? The Case of Incheon, South Korea. *Wind* **2022**, *2*, 210–220. https://doi.org/10.3390/wind2020012

Academic Editors: Zeljko Djurisic and Andrés Elías Feijóo Lorenzo

Received: 28 February 2022
Accepted: 14 April 2022
Published: 18 April 2022

1. Introduction

Worldwide, wind energy production is growing every year. It increased from 181 GW in 2010 to 743 GW in 2020 [1]. According to predictions, wind energy production globally in 2030 will be more than 2000 GW [2]. South Korea has declared its target is to reduce greenhouse gas emissions by 30% to meet their nationally determined contribution target by 2017 [3]. The target was updated, and it has also been announced by the government that by 2030 the country should generate 12 GW of wind power [4]. The Renewable Energy 3020 Implementation Plan (RE3020) was announced by the Korean government, with the aim of decreasing the proportion of coal and nuclear power generation and increasing power production from renewable energy sources [5]. The Third Energy Master Plan in 2019 and the Ninth Basic Plan for Power Supply Demand in 2020 were introduced to increase the share of renewable energy share in Korea [6]. In 2020, the Korean New Deal was introduced as a national development strategy to accelerate the country's transition towards a low-carbon and eco-friendly economy. In the same year, the Ministry of Trade, Industry and Energy (MOTIE), the Ministry of Oceans and Fisheries (MOF) and the Ministry of Environment (MOE) jointly published a "Plan for Offshore Wind Power Generation in Collaboration with Local Residents and the Fishing Industry" (OSW Collaboration Plan) to share the economic benefits of offshore wind project developments and to simplify permitting and licensing procedures [7]. Furthermore, South Korea announced—only a few days after Denmark announced their energy islands worth EUR 30 billion [8]—that it has plans for 8.2-GW offshore wind power projects [9]. Consequently, these activities have resulted in greater investment for wind energy projects in South Korea.

2. Strategy and Project Aim

The paper points out that offshore wind is not the same opportunity for every investor the way it is developed today. The paper presents, via the viewpoint of the Korean government, that there are projects that can and others that cannot be viable in the long term, depending on support and other factors.

2.1. Fixed-Bottom Wind Farm Site—Incheon

Wind energy is a zero-carbon electricity generation source, and also is an essential element in Korea's ability to meet its ambitious greenhouse gas reduction goals together with securing energy resources. Korean offshore wind projects benefit from the three bodies of water that surround the country and offer more benefits than onshore wind projects [10]. On 17 July 2020, the MOTIE, MOF and MOE jointly published the OSW Collaboration Plan [11]. This plan prioritized five regions in South Korea in which to develop offshore wind farm activities. Their mean wind speed and mean power density of the five regions are shown in Table 1. As shown in Figure 1, these regions are Incheon, North Jeolla, South Jeolla, Ulsan and Jeju Islands. Figure 1 illustrates how the mean water depth at the Incheon sites is approximately 25 m. Since a fixed bottom foundation is generally used at water depths below approximately 60 m [12,13], it is expected that fixed-bottom offshore wind turbines will be installed in the Incheon location. Therefore, the aim of this paper is to evaluate a fixed-bottom offshore wind project (500 MW) in Incheon, South Korea, and to consider its economic feasibility for use in large-scale wind farms.

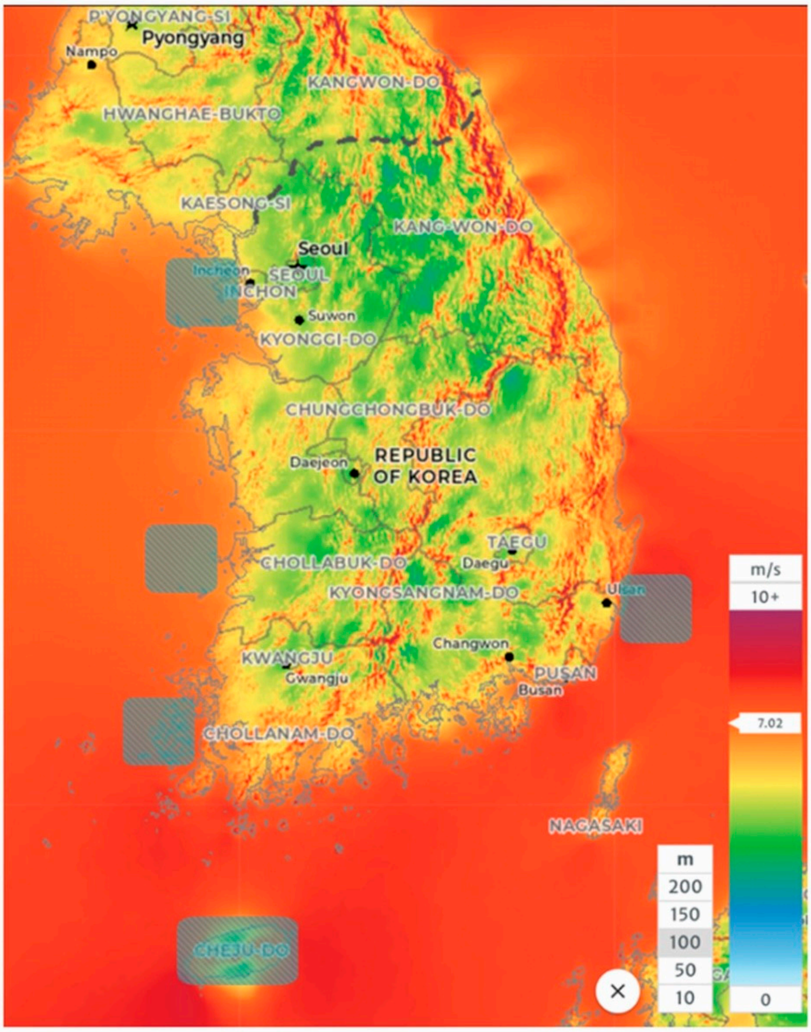

Figure 1. Mean wind speed and mean power density of the five regions [14].

Table 1. Mean wind speed and mean power density of the five regions [14].

At Heigh 100 m	Incheon	South Jeolla	North Jeolla	Ulsan	Jeju
Mean Wind Speed (m/s)	6.98	7.77	6.79	7.81	7.51
Mean Power Density (W/m^2)	439	538	469	722	525
Water depth at site (m)	25	55	-	140	105
Type of Offshore Wind Farm	Fixed-bottom			Floating	

2.2. *South Korea's Renewable Energy Policies (Offshore Wind Energy)*

South Korea recently declared its aim to become carbon neutral by 2050 and announced a range of strategies to meet this target in the renewable energy sector [15]. In this section, the strategies, plans and policies that are directly connected to offshore wind energy are described and analyzed.

2.2.1. Renewable Energy Portfolio Standard (RPS)

The Korean government announced its Renewable Portfolio Standard (RPS) in 2012. This was a national scheme to support offshore wind development in Korea [16]. According to the RPS, energy suppliers with a power generation capacity greater than 500 MW should produce a certain proportion of their total power from renewable sources. Figure 2 shows that the minimum proportion of RPS obligations was 3% of total power production in 2015, with a gradual increase to 25% by 2026 [17]. Energy suppliers that are not able to meet their RPS obligation are forced to pay penalties as much as 150% of the Renewable Energy Certificate (REC) price. Alternatively, they can purchase Renewable Energy Certificates (RECs) (per 1 MWh) in order to fulfill their initial targets.

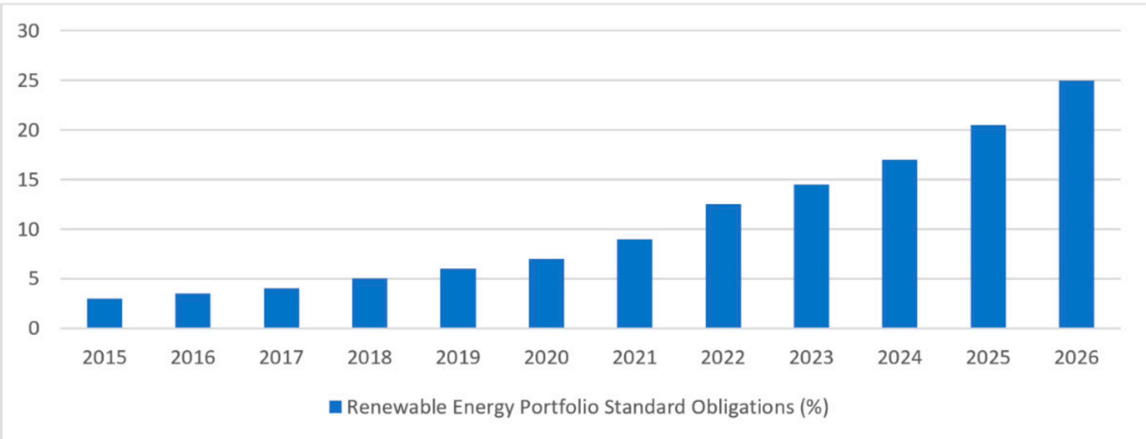

Figure 2. Renewable Energy Portfolio Standard Obligations [18].

2.2.2. Renewable Energy Certificates (REC)

RECs are a market-based tool, whereby the energy suppliers can receive an economic incentive while using renewable energy sources for electricity generation in South Korea. Depending on the renewable energy sources and the location of power plants, the final REC price is decided according to the REC weighting scheme [19]. According to the RPS and REC schemes, the total energy sales from the power production is calculated according to the sum of wholesale system marginal price (SMP) of electricity and the sale of REC price [20]. Figure 3 shows the trends of mean SMP prices in South Korea between 2002 and 2021 [21], and Figure 4 indicates the trends of mean REC price in the same period [22].

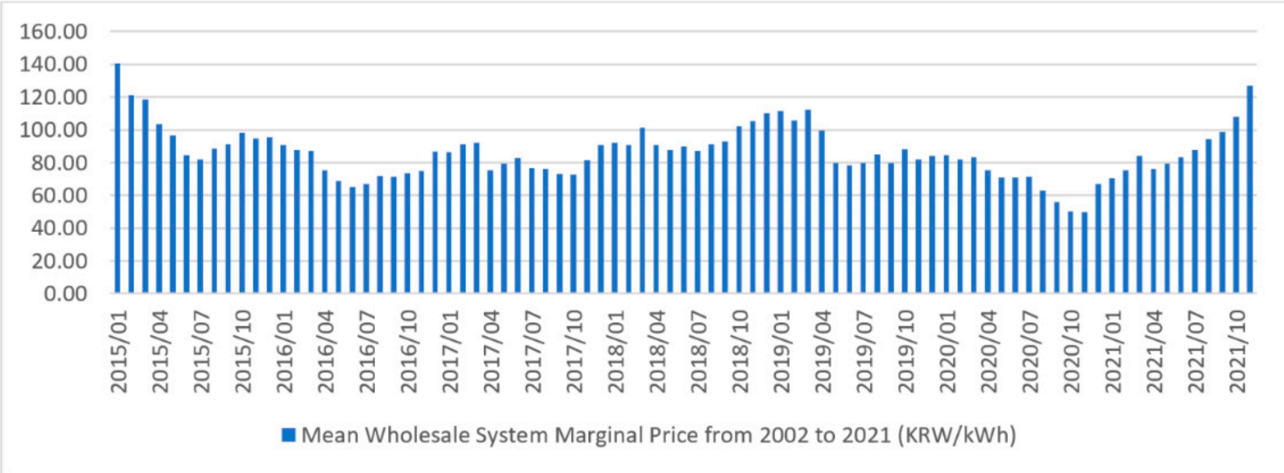

Figure 3. Trends of mean SMP from 2002 to 2021 [21].

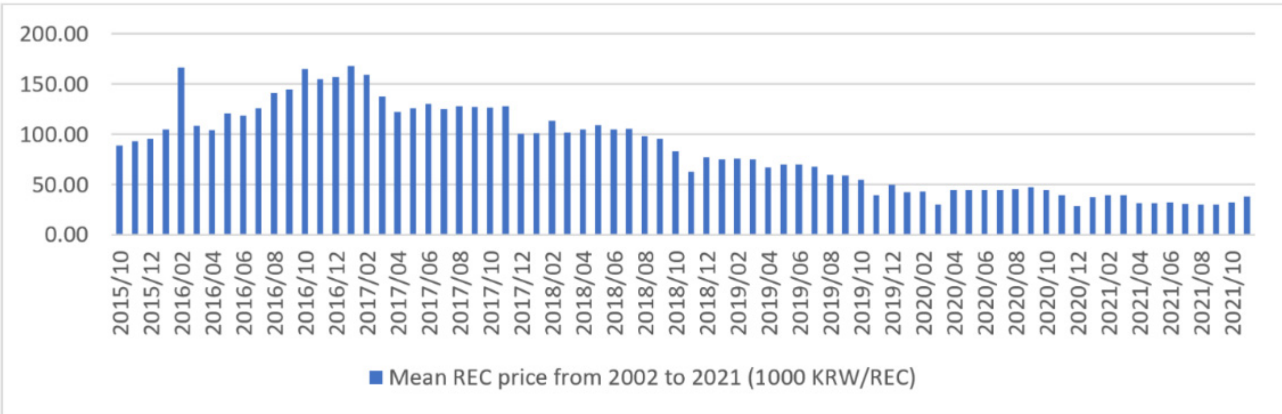

Figure 4. Trends of mean REC price from 2002 to 2021 [22].

Under the current PRS, energy suppliers have a fixed price contract, which is a combination of SMP and REC prices; the final REC price should be multiplied by REC weighting factors. As shown in Figure 4, the REC price has decreased since 2016. As of December 2021, the price is less than KRW 40,000 per 1 REC. As SMP and REC prices can have a critical impact on net present value (NPV), internal rate of return (IRR) and levelized cost of energy (LCoE) of renewable projects, these values are very substantial for wind developers and independent power producers in evaluating any upcoming wind projects in South Korea.

2.2.3. Renewable Energy 3020 Implementation Plan (RE3020)

The RE3020 describes the government's target to produce 20% of energy with renewables by 2030 [23]. In 2017, MOTIE announced the Korean government's detailed plans to increase the level of renewable energy capacity from the current levels of 7.6% (13.3 GW) to 20% (20.1 GW) of total power generation by 2030, creating relevant jobs in the renewable energy sector [24]. According to MOTIE's report in 2017, the aim of the plan is to support the deployment of large-scale renewable energy projects, including an increase in the capacity of wind power from 1.2 GW to 17.7 GW by 2030.

2.2.4. The Third Energy Master Plan and the Ninth Basic Plan for Power Supply and Demand

The Energy Master Plan outlines the government's main focus to tackle climate change and secure a stable energy supply. In June 2019, MOTIE published its Third Energy Master Plan with a focus on the innovative transition of the overall energy system from production and distribution to consumption [6].

In December 2020, MOTIE published the Ninth Basic Plan for Power Supply and Demand with the aim of increasing its renewable energy share from 15.8% (20.1 GW) of power capacity in 2020 to 40.9% (77.8 GW) in 2034. The total share of renewable energy is targeted to increase to 77.8 GW by 2034, which includes 45.6 GW of solar energy and 24.9 GW of wind energy. These will account for 91% of the total renewable energy share. Figure 5 illustrates the government's plan for renewable energy development plan in South Korea by 2035 based on the Ninth Basic Plan for Power Supply and Demand.

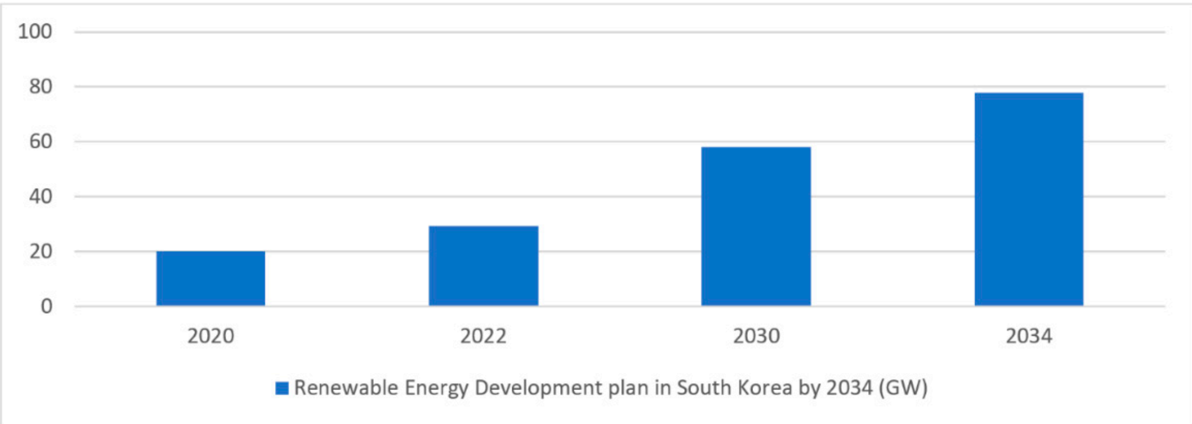

Figure 5. Renewable energy development plan in GW in South Korea by 2035.

2.2.5. The Korean New Deal

The Korean New Deal was introduced in July 2020 by the Korean government as a national development strategy. Under the Korean New Deal, there are two main policies: the Digital New Deal and the Green New Deal [25]. The Digital New Deal promotes digital innovation and dynamics in the Korean economy, and the Green New Deal accelerates the transition towards a low-carbon and eco-friendly economy [26]. To strengthen employment and support the structural transition towards a digital and green economy, the government aims to invest KRW 160 trillion of governmental support and to create 1,901,000 jobs by 2025 [27]. It is also reported by the Ministry of Economy and Finance [28] that the total project cost for the Green New Deal is KRW 73.4 trillion. This is also expected to create 659,000 jobs in the same time frame.

2.2.6. Fishing Industry Collaboration

In July 2020, MOTIE, MOF and MOE announced their OSW Collaboration Plan, with a target of increasing the capacity of offshore wind power up to 12 GW by 2030 and sharing the economic benefits of offshore wind projects with local residents and the fishing industry. Under the current energy policy in Korea, the wind project developers are responsible for all project development activities such as permissions and application for approvals. Therefore, the process is not considered very efficient for the developers. However, as the simplification of licensing procedures is included in the plan, this implementation could reduce the potential risk for developers.

3. Methods

This work focused on identifying whether the case of Incheon was only dependent on subsidy and governmental support, or if the project could become viable with minimum or even no support. The governmental support mechanisms were already regarding renewable energy policies and the introduced RPS, and the more recent Korean New Deal and its implementation was performed under various scenarios. The NPV, LCoE and IRR indexes were calculated based on the project's specific particularities, such as distance from shore, REC Weighting, sea depth and the power purchase agreement (PPA), and based on these scenarios, an index-based comparison was revealed. Based on this, the viability of each scenario and the margin for profitability for such an investment were discussed. Under a clear and precise analysis of how the experiment was completed, the approach can be applied to all offshore-planned or conceptual-stage projects in the country.

4. Analysis and Results

Under the current strategies in South Korea, an extensive analysis was performed, starting from the LCoE for the Incheon wind project, shown in Figure 6.

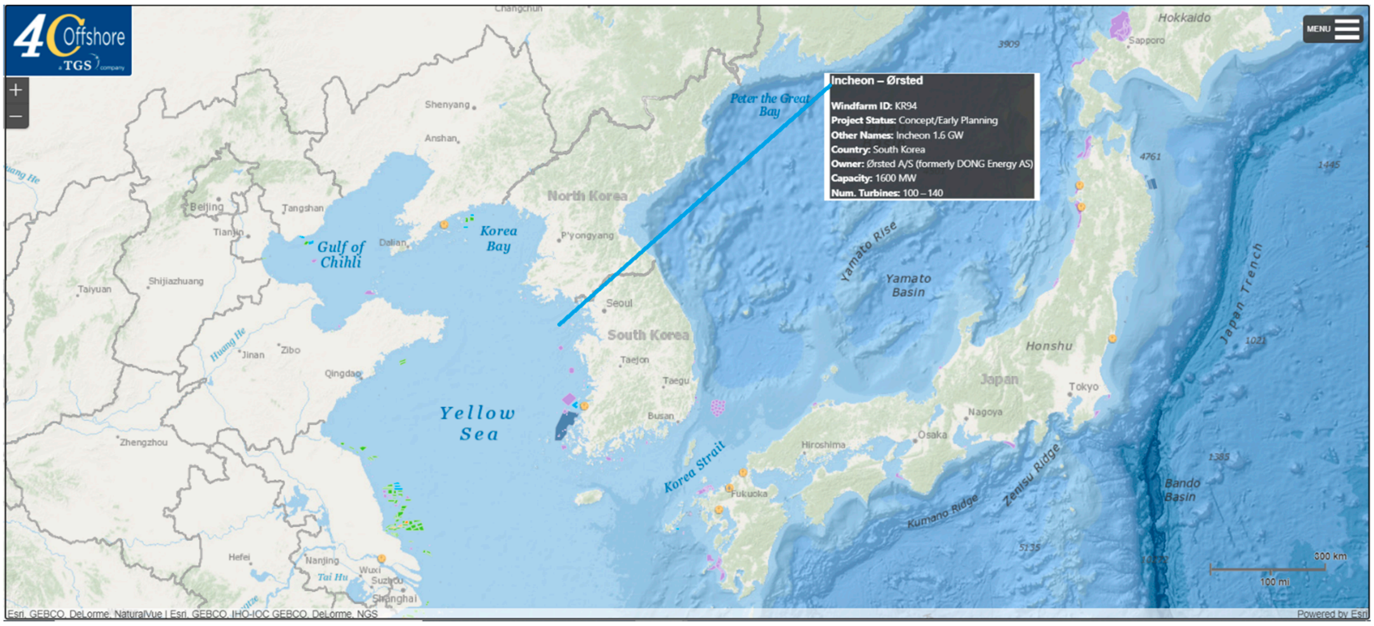

Figure 6. Details of the Incheon Wind Project (retrieved from 4coffshore).

The project is in its early planning phase and the owner is Ørsted A/S; although its capacity has not yet been fixed, it has been studied with a capacity of 500 MW.

4.1. LCoE for the Incheon Wind Project

According to Lai et al. [29] and the detailed analyses of Kocsis and Xydis [30] and Enevoldsen et al. [31], LCoE is calculated based on Equation (1):

$$LCoE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}, \quad (1)$$

where:

I_t = Investment expenditures in year t

M_t = Operations and Maintenance expenditures in year t

E_t = Electricity generation in year t

r = Discount rate

n = Life of the wind turbine systems.

The basic information of the Incheon wind project is shown in Table 2.

Table 2. Basic Project Information.

Category	Value	
Period	2024–2053	Year
Capacity	500	MW
Capital Expenditure (CAPEX) [32]	3,837,000	USD/MW
Operating Expenses (OPEX) [32]	51.92	USD/MWh
Net Capacity Factor [32]	38.80	%
Tax Rate [33]	22.00	%
Inflation [34]	2.00	%
Discount Rate [35]	6.00	%
Debt term [33]	15	Years
Debt Fraction [33]	70	%
Depreciation in Korea: Straight-line method [36]	5	%/year

Combining all the basic details of the project (Table 2), the different REC weighting schemes by the Ministry of Trade, Industry and Energy (Table 3), and knowing the SMP (taken at 80 KRW/kWh), REC at 30.2 KRW/kWh and the REC weight at 2.5—according to the basic REC weighting scheme for an offshore wind farm (Table 3)—the PPA was calculated as below (Equation (2)):

$$PPA = SMP + 1REC = SMP + REC \cdot (REC\ Weight), \tag{2}$$

Table 3. REC Weighting Scheme for Wind Farm [18].

Category	Criteria	REC Weighting
Onshore	-	1.2
Offshore	-	2.5
Offshore	grid connection $\geq$ 5 km and water depth $\geq$ 5 m	+0.4 per 5 km and 5 m (Max. 3.5)

The PPA is calculated at 155.5 KRW/kWh, which is equal to 130.45 USD/MWh (Table 4).

Table 4. PPA in South Korea [22].

Category	Value	
SMP	80	KRW/kWh
REC	30.2	KRW/kWh
REC Weight	2.5	
SMP + 1 REC	155.5	KRW/kWh
PPA = SMP + 1 REC in USD	130.45	USD/MWh

(exchange rate: 1 USD = 1.192 KRW).

4.2. Scenarios

Based on well-known cash flow models [37,38] the NPV and IRR indices were calculated in different scenarios. The NPV provides a comparative way to evaluate capital or financial products based on their current cash flows and is given by the formula (Equation (3)):

$$NPV = \frac{R_t}{(1+r)^t}, \tag{3}$$

where:

R_t = net cash flow (inflow-outflows) in year t

t = year of the cash flow

The IRR index is another way to assess the viability of future investments. The scope is to identify the rate by which the investor will get their capital back and it is calculated via the formula (Equation (4)):

$$IRR = \sum_{t-1}^{t} \frac{C_t}{(1+r)^t} - C_o, \tag{4}$$

where:

C_t = Net Cash inflow in year t

C_o = total capital cost

Using the parameters from the project information, and in the examined case that the REC weight equals 2.5, the LCoE was calculated at 129.97 USD/MWh with a positive NPV of 147.14 KRW/kWh and a 17% IRR. After the calculations, the results of the two different scenarios are shown in the table (Table 5) and figure (Figure 7) below.

Table 5. A metric-based comparison of the different scenarios.

	PPA [USD/MWh]	NPV [KRW/kWh]	IRR [%]
IF REC Weight = 1.0	92.45	−207.22	9
IF REC Weight = 0.0	67.11	−443.47	2

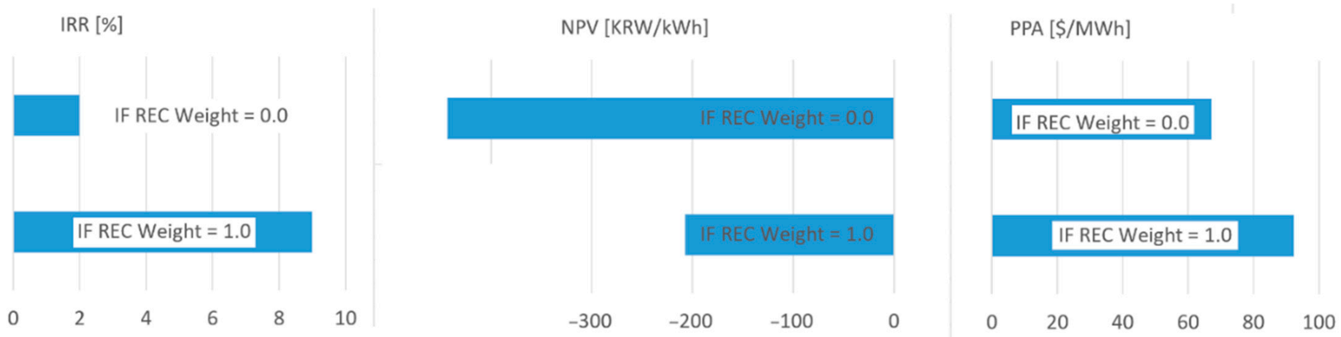

Figure 7. Metric (PPA, NPV, IRR)–based comparison.

5. Discussion

When can such a project be regarded as a viable project? With the inclusion of the REC economic weight, the project can be considered economically competitive, as the LCoE is lower than the combination of "SMP + 1 REC", which is 130.45 USD per MWh. However, in order to evaluate the commercial feasibility of the project [39], it is important to consider the REC weight. For example, when the REC weight is 1.0, the sum of "SMP + 1 REC" becomes 92.45 USD per MWh and IRR decreases to 9%. If the Korean government decides not to support the REC weight (REC = 0), the sum of "SMP + 1 REC" is 67.11 USD per MWh and IRR reduces down to 2%. A 2% IRR is considered rather low and most probably non-profitable [40]. This is also explained by the fact that the NPV costs in both scenarios have negative values. Practically, an investor would never go forward with an investment with such low profitability margins. On top of that, such demanding offshore projects that have a history of less than 25 years—and a lot shorter mature history—usually carry many risks [41]. Unexpected or increased faults during the 20–25 year lifetime of an offshore wind farm can completely eliminate this 2% or even end up to be a negative IRR and thus definitely not a viable project [42].

Therefore, the current Korean approach to subsidizing renewable energy development is substantial and the only viable way for foreign and domestic developers in terms of evaluating the forthcoming large-scale offshore wind projects in South Korea. In order for subsidy to be minimal for such projects and still be viable as investments in the long term, a "coalition" with hydrogen (or methane) production and stronger links with other sectors, such as the transportation sector, is needed [43,44]. This could make offshore projects, specifically the one in Incheon, more viable. However, a detailed analysis on the topic is not included in this work and it will be the focus of a future paper.

6. Conclusions

Through long-term contracts with renewable energy companies, the feed-in tariff support scheme was used in order to accelerate investments in various renewable energy technologies over the last twenty years or so; over the last decade, there has been a transition from the tariff support scheme to premium or other support schemes worldwide [45]. However, manufacturing costs for both wind turbine and solar panel projects have declined, and in most countries this support mechanism was removed and the wind and solar projects—since they started being considered mature and competitive technologies—did not require support at all. Yet, offshore wind projects did not follow exactly the same path of lower costs, and this is forecasted for much later [46]. Their cost remained higher compared to onshore projects, and still requiring governmental support [47]. In this study, the NPV and the IRR were calculated in Incheon, South Korea, proving that with limited or no governmental support the IRR could be between 2 and 9%, which could lead to negative value projects. This proves that on a large-scale, the offshore industry cannot be based on zero subsidy and one way or another it will often require support. Therefore, independent power producers are looking for ideas/concepts that could unconventionally self-support the industry. Concepts such as Denmark's energy islands, which will also produce hydrogen that will afterwards be transported to shore, should lead to more green and viable investments in a politically and economically fragile environment [8,48]. Concepts such as hydrogen (or even methane) production in offshore sites are gaining attention and cause all developers to think that they should be building underwater pipes, not just cables. In the case of zero subsidy, there is a need to jointly develop energy sources, such as hydrogen storage, together with wind or solar energy. Such an alliance can lead the project's IRR closer to 9% or more and minimize the payback period.

Author Contributions: Conceptualization, J.L.; validation, G.X.; formal analysis, J.L.; resources, G.X.; data curation, J.L.; writing—original draft preparation, J.L.; writing—review and editing, G.X.; visualization, J.L. and G.X.; supervision, G.X.; project administration, G.X. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The study did not report any data.

Conflicts of Interest: The authors declare no conflict of interest.

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