# Feasibility of Taiwan's Offshore Wind Power Development

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## Abstract

Harnessing renewable energy sources such as wind energy can strengthen a country's energy security while also curbing environmental degradation. For these benefits, Taiwan aims to develop its potential offshore wind power by promoting wind turbine applications. To meet its wind power installation targets, the government implements feed-in tariffs (FITs) policy, offering subsidies on capital, and funding research and development. At present, there is still a wide gap between the country's installed offshore wind capacity and the long-term government targets due to economic risks and geographic uncertainties. This paper aims to develop an analysis framework to support a full-range techno-economic and cost-benefit analysis for Taiwan's offshore wind power development. This paper performs both cost-benefit and computable general equilibrium analyses. To support policy formulation in related agencies, this study also provides suggestions on how to commercialize the developed wind turbine technologies, and how to create an industrial chain based on the results.

Keywords: cost-benefit analysis, offshore wind power, Taiwan, computable general equilibrium model

JEL Codes: Q 41, Q43, Q48

# 1. Introduction

Taiwan imports more than 98% of its energy requirements (BOE, 2015). As such, harnessing renewable energy sources is one of the most important ways to strengthening its energy security while also curbing environmental degradation. Being an island country, Taiwan has limited land but wide sea area, which makes offshore wind power a promising energy source for Taiwan. At present, there is still a wide gap between the country's installed offshore wind capacity and its long-term policy targets. As indicated by many researchers, economic barriers are the primary impediment to the application of renewable power systems (for example, Burtraw and Krupnick, 2012). Particularly for offshore wind turbines, geographic uncertainties often deter the confidence of potential wind farm operators.

However, several policy incentives have been proposed and applied to encourage the adoption of distributed renewable power systems. Popular implementation tools include feed-in tariffs (FITs), subsidies on research and development (R&D) and capital investment, and implementation of renewable portfolio standards (Solangi *et al*., 2011). Among these strategies, the FIT is usually regarded as the most effective mechanism (del Río and Gual, 2007; Klein, 2008; Couture and Gagnon, 2010; Lin *et al*., 2014).

The Taiwan government has shown its support for wind power development through its passage of the Renewable Energy Development Act (REDA)[1] and implementation of FIT mechanisms. Even with these policies in place, Taiwan's installed offshore capacity has zero growth until now. For both the government and investors, understanding the possible concerns about the deployment of offshore wind farm is important for utility planning, accommodating grid capacity, designing financial incentives, and formulating future climate adaptive policies.

Snyder and Kaiser (2009) and Shaahid *et al*. (2013) explored the cost and benefit of wind power system installations. However, it is also important to examine the potential interactions among energy, economy, and environment when developing offshore wind power. The main objective of this paper is to provide a complete set of information about the potential contribution of offshore wind power to Taiwan's electricity requirements, as well as the potential costs of its deployment. By building a computable general equilibrium (CGE) model, this paper can further measure the contribution of R&D and FIT to the country's installation of offshore wind power. In short, we aim to develop an analysis framework to support a full-range techno-economic and cost-benefit analysis for Taiwan's offshore wind power development. Both cost-benefit and computable general equilibrium analyses are performed. Suggestions on how to commercialize the developed wind turbine technology and on how to create an industrial chain for wind turbines are provided based on the results.

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[1] The Act was approved by the Legislative Yuan (Taiwan's congress) in June 2009. Its purpose is to promote renewable energy and to foster its long-term sustainability (see Article 1 of the Act).

The rest of the paper is organized as follows. Section 2 describes the status and promotion strategies for wind power systems in Taiwan; Section 3 presents the results of cost-benefit and computable general equilibrium analysis. Section 4 discusses the results and implications for offshore wind power development in Taiwan; Section 5 concludes.

## 2. Status and Promotion Strategies for Wind Power in Taiwan

In 2009, the Dawning Green Energy Industry Program mapped out the blueprint for Taiwan's future low-carbon energy development. Based on that, 10% out of the 500 billion NTD budget of the 4-year "Economic Revitalization Policy Project to Expand Investment in Public" were allocated to the development of green energy. In 2012, the Offshore Demonstration Incentive Program (DIP) and Thousand Wind Turbines' Project were officially announced (BOE, 2012). Article 6 of the "REDA" set a renewable energy target of 6,500-10,000 MW of domestic installed capacity, and began implementing the FIT mechanism in 2009. Taiwan has the ambition to install around 3,000 MW of offshore wind turbines by 2030 to avoid possible land use problems for onshore wind turbines and PV, and these measures have set the foundation for Taiwan's offshore wind energy development.

Currently, Taiwan seeks to boost private sector investments in accordance with the relevant provisions in the "REDA" through the use of the FIT mechanism, which is the incentive tool of choice modeled by various countries around the world (Río and Gual, 2012). There are two main types of FIT policies that can be applied to promote power generation from renewable energy sources. The first type is a fixed FIT, which purchases power from independent power producers using the market price, plus a fixed amount over a fixed period. The second type is a premium FIT, which pays the market price plus a percentage of that amount (Klein, 2008). The Taiwan government adopted the former.

In order to incentivize the companies to install offshore wind farms that are more uncertain than onshore ones, the FIT must be 2 times higher than onshore ones. The FIT rates for offshore wind power generation have been stabled from 2010 at around 5.60 NT$/kWh. While the government has been reducing the purchasing rates of other types of renewable energy sources every year, it did not do so for offshore wind power. This is because investors are still uncertain whether the current FIT is enough to compensate for the financial and operating risks relating to wind farms.

## 3. Methodology

(1) Cost-Benefit Analysis

Wind power generation makes use of wind energy and thus has no variable cost of fuel. The generation costs can be calculated by adding the total operational costs and the investment cost discounted based on a 20-year life cycle. We computed the power generation costs of each wind turbine without considering taxes. The formulas are shown below (Chen *et al*., 2010; Lin *et al*., 2014):

$$C = (FC + VC)/h,$$
$$VC = FC \times M,$$
$$FC = I \times CRF(r,n), \tag{1}$$
$$CRF(r,n) = \frac{r(1+r)^n}{(1+r)^n - 1},$$

where $C$ denotes the levelized cost of wind electricity (NTD/kWh); $VC$ is the annual variable cost (NTD/kW per year); $FC$ is the annual fixed cost (NTD/kWp per year); $h$ is the annual full-load working hours (hours/year); $M$ is the operating and maintenance expense ratio (%); $I$ is the investment cost (NTD/kWp); $CRF$ is the capital recovery factor; $r$ is the reasonable profit rate (discount rate, %); and $n$ is the life span of wind equipment measured in years.

The demonstration wind farms proposed by the Ministry of Economic Affairs (MOEA, 2012) are used as the basis for a techno-economic analysis (the Siemens module SWT-3.6-120). Using wind data statistics and the investment costs of wind system deployment projects (see Table 1), the power generation costs of offshore wind are calculated using Eq. (1), and serve as the basis for the construction of the supply curve for Taiwan's offshore wind turbine installation.

The offshore wind supply curve attempts to estimate the relationship between the cost of wind turbine and the quantity of installation at or below that cost. If the power generation cost of wind power can compete with that of traditional electricity sources, the quantity at or below that cost would be determined by the supply curve. This permits a generalized treatment of deployment potential in the cost analysis, and provides a consistent accounting framework.

Table 1 Financial Parameter

| Parameter | Value | Source |
|---|---|---|
| Installation cost | NT$158,500/kW | BOE (2013) |
| O&M cost | 3% capex pa | BOE (2013) |
| Project life | 20 years | BOE (2013) |
| Capacity factor | 26.2-49.5% | The estimations of capacity factor in proposed sites[a] based on ITRI's (2012) Wind Data Statistics. |
| Discount rate | 5.25% | BOE (2013) |

[a]The demonstration wind farm sites proposed by MOEA (2012) located near water areas of around 5-20 meters deep in Miaoli, Changhua, Penghu, Yunlin, Chiayi, and Tainan.

(2) Computable General Equilibrium Analysis

In this paper we also make use of the GEMEET (General Equilibrium Model for Energy, Environment and Technology analysis) model developed jointly by the Center of Applied Economic Modeling at Chung Yuan Christian University and the Institute of Nuclear Energy

Research (INER), Taiwan to conduct some scenario analyses relevant to offshore wind power development. The model is a recursive dynamic general equilibrium model with detailed specification of renewable energy technologies and sectors. The model is formulated with the linear transformation technique of Johansen (1960), which transforms the original nonlinear equations with level solutions into the linear equations of percentage change. This procedure simplifies the technique required in solving for the equilibrium and makes it feasible for economists to develop and solve a more detailed model. Consequently, the solution can easily be reverted from the solution of percentage change to the solution of value without much trade-off in accuracy.

This model retains the basic features of a typical dynamic CGE model with several important extensions. These include (1) detailed specification of major new and renewable energy equipment and power generation technology, such as bio-ethanol, bio-diesel, solar PV (photovoltaic), onshore wind power, offshore wind power, IGCC (integrated-gasified combined cycle) with CCS (carbon capture and storage), etc.; (2) taking into account the learning effect especially for new and renewable energy sectors, and specifying functions that link cumulative production and R&D investment with total factor productivity; (3) econometric estimation of some key parameter values in the model (Lin *et al*., 2009); and (4) inclusion of the subsidy mechanism to power generation, such as the FIT scheme. [2]

Our model is benchmarked to 2006 and updated to the main economic and energy variables of 2013 through historical simulations. To include some new and renewable energy sectors in the model (including PV, onshore and offshore wind power), and to distinguish different types of refined petroleum products and power generation technologies, we adjusted the input-output tables to include exogenous data on cost and sales for industries. The total electricity generated is sold to the sole electricity distributor, which distributes electricity to all other sectors of the economy.
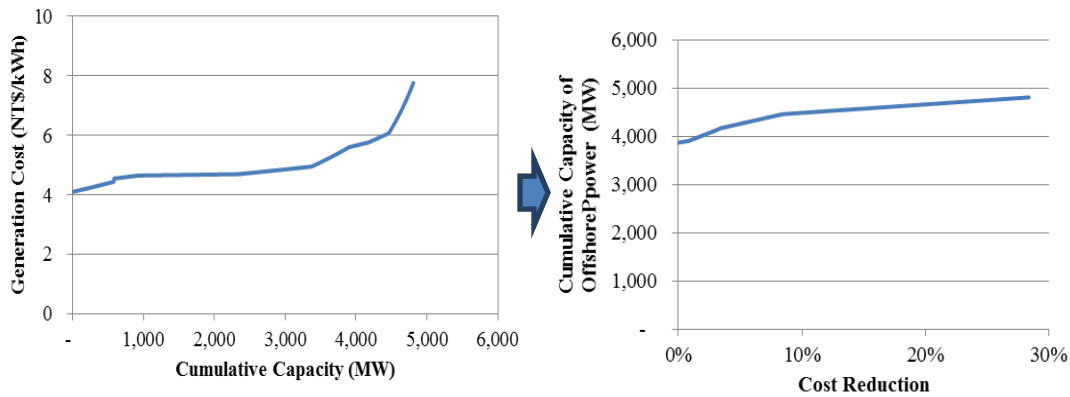
In this paper, we considered several scenarios involving FIT policy and R&D investment to assess the feasibility of the government's renewable energy promotion targets in the following technologies: solar PV, onshore wind power, and offshore wind power. Finally, we compare the benefits in the various scenarios based on several indicators.

## 4. Results and Discussions

The economic risks and geographic uncertainties of deployment and operation of offshore wind farms are great challenges shared by countries around the world. To reasonably assess if certain areas are suitable for installing wind turbine, exploring the economic feasibility of installation is necessary. Our results has showed that the unit cost of offshore power in the wind farms proposed by government range from 4.09 to 7.74 NT$/kWh (see Figure 1). The suggested

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[2] See Lin *et al.* (2015) for a more detailed description of the model.

priority sites are Changhua, Penghu, and Yunlin, which have more abundant wind resources than other areas.



(a) Supply Curve of offshore power   (b) Cost reduction required in offshore power

Figure 1 Relationship between deployment and required cost reduction of offshore power

The 2014 FIT rate of offshore wind power proposed by BOE is 5.6076 NT$/kWh. Below this rate, our estimation presents that 3,931 MW of wind turbines could be deployed.

Cost reduction rate = (offshore power generation cost -5.6076 NT$/kWh) / offshore power generation cost

We evaluate the investments required based on capital budgeting measures, assuming a constant selling price of 5.6076 NT$/kWh according to 2014 FIT of offshore wind power for the operators. If 3,931 MW of wind turbines below the cost of 5.6076 NT$/kWh can generate power, then the benefit-cost ratio (B/C) would be 1.92, higher than 1 at the national level. This implies that if the total cash inflow during the 20-year plant lifespan is greater than the total cash outflow, then it may be a sound investment for the government. Compared with Europe's generation cost (see Figure 2), Taiwan's offshore wind power has great potential to be deployed.

In practice, investors still face uncertainties in securing government permits, in profitability, and in operations. Moreover, the government will gradually lower the rates of FIT for offshore rather than keep the rate constant due to fiscal burdens. Lowering these risks can be a direct solution to make offshore power generation a reality as soon as possible in Taiwan. Our results show that among these challenges, financial risk or the O&M cost (constituting 25% of power generation cost) would be the most crucial challenges to overcome before wind farm operators will be willing to participate in the project.
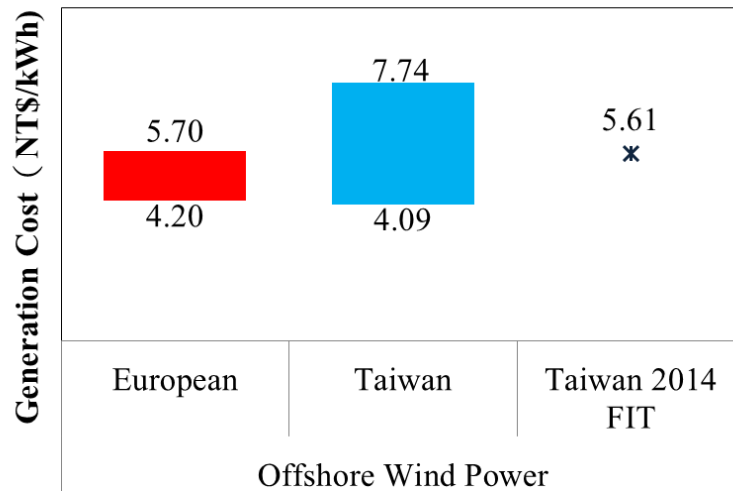
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Figure 2 Comparison of offshore power cost

Aside from cost-benefit analysis, this paper also applies the GEMEET model to comprehensively discuss the relationship between FIT policy and R&D investment and the government's renewable energy promotion targets. Table 2 inspects how much additional R&D investment is still needed to meet the policy targets for renewable generation under the FIT scheme. The results show that significantly increase the growth of R&D investment in the initial stages of offshore wind power technology development is needed. In 2013-2015, an annual growth rate of around 45%, as compared to 6.67% in the other two renewable sources, might be needed to inject enough momentum to the industry in the early stages. Through the learning effect and future innovations in the industry, the government's financial obligation to support R&D can be reduced in the mature period (2026-2030).

Table 2 Required R&D Investment Growth Rate of Renewables

| Unit: % | 2013-2015 | 2016-2020 | 2021-2025 | 2026-2030 |
|---|---|---|---|---|
| Solar PV | 6.67 | 6.67 | 8.41 | 7.32 |
| Onshore Wind Power | 6.67 | 6.67 | | - |
| Offshore Wind Power | 45.20 | 52.24 | 11.12 | 5.05 |

This table shows the required R&D investment growth rates to achieve the policy target of renewable deployment under current FIT mechanism.

While an increase in R&D investment can reduce the cost of renewable technology and, hence, the subsidy given by the government, accelerating the decline in subsidy level should be matched by an even more aggressive investment scheme for renewable technology in achieving

the promotion targets. Figure 2 shows the trade-offs between the R&D investment and FIT policy for offshore wind power, although these two schemes are also available for the development of renewable energy.
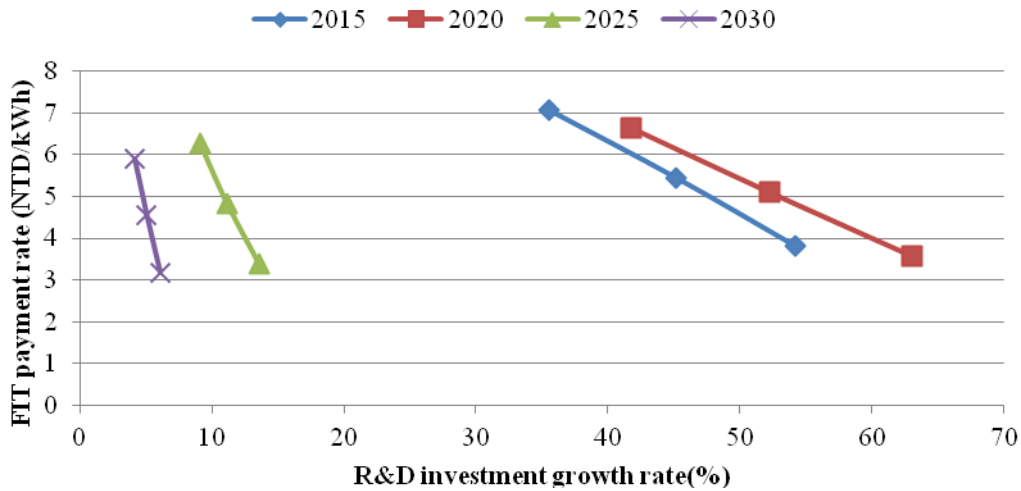


Figure 3  Optimal Combination of FIT and R&D to Achieve the Promotion Targets of Offshore Wind Power

The government should invest more R&D in this industry's early stages to speed up its technological advancement, as shown in Figure 3. It is hard to reach the policy promotion targets using only an FIT incentive mechanism, especially for offshore wind power. Compared with other renewable technologies, offshore wind power is still in its early phase of deployment, which may deter investors from participating, considering the uncertainties in securing government permits, in profitability, and in operations.

## 5. Conclusions

This paper aims to provide policymakers with assessment tools to simulate concrete scenarios and optimal conditions that would advance offshore wind power as a viable renewable energy source in Taiwan. To do so, we construct an offshore power supply curve to conduct a techno-economic assessment of the wind farm sites proposed by Taiwan's government (MOEA, 2012). To explore the possible learning effect of offshore technology under the FIT and R&D incentive mechanisms, we also employ the GEMEET model with detailed specification for renewable energy technology and sectors.

An appropriate FIT needs to consider both the policy targets and the expected rate of technological progress. Our offshore supply curve (Figure 1) suggests that the current FIT mechanism may be sufficient to draw the attention of potential wind farm operators, and that the O&M cost of offshore wind system in Taiwan can greatly influence the investment behavior of wind farm operators. As revealed by the GEMEET model results, the government needs to invest more on offshore wind power's R&D during its early stages of deployment to speed up its

technological advancement, hence addressing the uncertainties faced by potential wind farm operators. It is difficult to reach the policy promotion targets using only FIT incentive mechanism, especially for offshore wind power. This is because offshore wind power is still in its initial stage of development, which has not yet tested in the market like other renewable technologies did.

In the early stages, the forthcoming financial or operating risks could impede the renewable energy's technological progress, hence R&D is one of the main driving forces of technological change. Consequently, the government should offer FIT incentives and invest in R&D to stimulate the development of renewable technology. While both strategies are effective in promoting renewable energy technology, we still need to know the optimum combination of R&D investments and FIT rate to achieve the policy promotion targets in the future. It is then crucial to examine the interactions of these incentives and policies.

To achieve the renewable energy targets, the government may set up an FIT payment rate annually to induce renewable energy generation from the private sector. It will stimulate the R&D and physical investments in renewable energy. Potential success of R&D efforts may improve current renewable energy technologies. This technological improvement may reduce the cost of installation in the future, and may help the government pay lower FIT prices. Hence, if the government accelerates the decline in its subsidy levels, they should match it with an even more aggressive investment scheme for renewable technology's R&D to achieve the promotion targets.

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