Applied Energy 217 (2018) 336–345

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Impact of government subsidies on economic feasibility of offshore wind system: Implications for Taiwan energy policies

Nguyen Thi Anh Tuyet*, Shuo-Yan Chou

Department of Industrial Management, National Taiwan University of Science and Technology, No 43 Section 4, Keelung Rd., Taipei 10607, Taiwan, ROC

HIGHLIGHTS

- Investigate impact of government subsidies on economic feasibility through economic criteria.
- Estimate the generated electricity under effect of inactive periods and real weather conditions.
- Assess the currently applied subsidies on capital cost and suggest a more appropriate set of subsidies.
- Assess the currently applied FIT subsidies and suggest for establishing regional FIT subsidies.

ARTICLE INFO

Keywords:
Offshore wind energy
Economic analysis
Government subsidies
CO_2 emission
Maintenance cost
Harsh weather condition

ABSTRACT

This paper proposes an approach to analyze the economic feasibility of offshore wind energy under influences of government financial subsidies, dynamic weather conditions (including typhoon), taxation, expectation of investor, optimal maintenance schedule, generated electricity under real weather conditions, and benefits from reduction of CO_2 emission. Economic criteria are calculated and used to assess efficiency of the government financial subsidies. This paper further proposes more appropriate subsidies for the government in term of satisfying both of investor's expectation and the government's target. In the case of Taiwan, government has been currently adopting Feed-in-tariff (FIT) subsidy and offering subsidy on capital cost to promote the development of offshore wind system. However, the currently applied subsidy on capital cost is not attractive enough for the investors and the current FIT subsidy is applied equally for all regions of Taiwan regardless the distinct conditions of each region. This paper proposes a more appropriate subsidy for capital cost, and suggests establishing regional FIT subsidy to subsidize differently for different regions. The results indicate that the proposed subsidy for capital cost and the proposed regional FIT subsidy are more appropriate to promote the expansion of offshore wind system.

1. Introduction

Offshore wind energy has been recognized as tremendously potential solution for replacing the conventional energy sources because it is inexhaustible and absolutely clean. A large number of countries have been establishing the related policies and subsidies to encourage the development of offshore wind energy. This is evidenced by a large number of offshore wind farms and the robustly increasing amount of research in wind energy in recent years. As the example shown in Fig. 1, cumulative installed offshore wind capacity increased from 801MW in 2006 to 3.01 GW in 2010, and reached 12.63 GW in 2016 (correlatively 3589 offshore wind turbines) [1]. Offshore wind is projected to grow to a total installed capacity of 24.6 GW by 2020 [1].

In the academic field, a huge number of studies on offshore wind energy have been published in recent years [2–20]. Although most studies show that offshore wind energy is technically feasible [21–30], only a handful of studies assess the economic feasibility of offshore wind energy under the real weather conditions, maintenance activities, and government subsidies. In fact, most of the studies merely rely on the data provided by the manufactures and some theoretical assumptions about the weather conditions and other uncertain parameters to calculate the generated electricity, assume the maintenance cost, and to calculate the corresponding economic criteria based on those assumptions [31–34]. For example: Liu et al. [33] and Yue et al. [34] proposed models to assess the economic feasibility of offshore wind energy based on an assumption that the maintenance cost is annually 2–3% of total cost. In practice, the maintenance cost of offshore wind system depends largely on the location (distance from the coast), wind farm size, type of

* Corresponding author.
E-mail addresses: anhtuyet213@gmail.com (T.A.T. Nguyen), sychou@mail.ntust.edu.tw (S.-Y. Chou).

https://doi.org/10.1016/j.apenergy.2018.02.137
Received 12 December 2017; Received in revised form 7 February 2018; Accepted 20 February 2018
0306-2619/

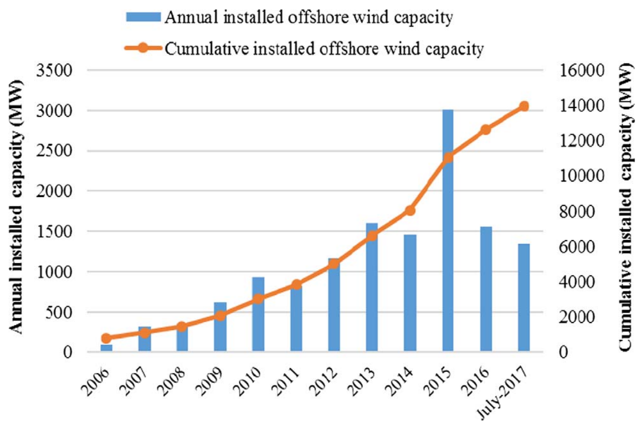

Fig. 1. Installed offshore wind energy capacity in 2006–2017.

turbine and weather conditions. Therefore, these above assumptions of Liu et al. [33], and Yue et al. [34] may negatively affect to the correctness and reliability of offshore wind assessments. In this paper, the maintenance cost is not obtained by some predetermined assumptions, but is calculated under impact of all factors (for example: location, wind farm size, type of turbine and weather conditions).

The assumptions based on theoretical data are usually incorrect and depart severely from the practical values. As a result, the economic evaluation based on those inaccurate assumptions generates a lack of accuracy and reliability for offshore wind system. Moreover, to the best of our knowledge, none of the studies that have been published considers the impacts of government subsidies, taxation, harsh weather condition (typhoon), expectation of investor, and the benefits of offshore wind energy in reducing other externalities (for example: reducing CO_2 emission), into the financial model to estimate the economic feasibility of offshore wind systems.

This paper arrives at an approach to analyze the economic feasibility of offshore wind systems, assess the efficiency of the government subsidies, and propose more appropriate subsidies for the government. The economic criteria are estimated based on estimating the generated electricity of offshore wind systems under real weather conditions. To improve the accuracy and reliability of economic criteria calculation, various influential parameters such as dynamic weather condition (including typhoon), taxation, expectation of investor, optimal maintenance schedule, time value of money, and the benefits of offshore wind energy in reducing CO_2 emission are all considered. We discover that the currently applied subsidies of Taiwan government have some deficiencies that can be improved by the proposed set of subsidies.

This paper is organized in four sections of which section one is the introduction about the economic evaluation on offshore wind system. Section two shows the proposed model. The efficiency of the model applied to Taiwan will be evaluated specifically in section three. Finally, the conclusions and policy implications are drawn in section four which provides a summary of this paper.

2. Methodology

2.1. Overview of the proposed approach

This paper establishes an economic model, which is subsequently used to analyze the possible setting of government subsidies so that a clearer and more certain financial justification can be provided to potential offshore wind system investors to alleviate the barrier of adoption. As illustrated in Fig. 2, government relies on the economic criteria to accommodate the subsidy polices by influencing to capital cost and the investor's benefit through Feed-In-Tariff. In other words, government adjusts the subsidy policies to adapt the economic criteria, thereby directly influencing the investor's decision.

There are three economic criteria used in this paper: Net Present Value (NPV), Internal Rate of Return (IRR) and Payback Period (PP). These economic criteria are calculated based on government subsidies and taxes, capital cost, practical generated electricity, maintenance cost, costs occur in typhoon occasions and some other influential parameters such as market electricity prices, and time value of money. To assess these economic criteria, cash flow is considered as the most essential factor. Cash flow is obtained based on the cost-benefit relationship of offshore wind system. The cost of offshore wind system is a summation of: (1) capital cost (considered under impact of government subsidy), (2) maintenance cost (failure rate is estimated by Weibull distribution), and (3) the cost occurs in a typhoon occasion. The benefit of offshore wind system is evaluated by: (1) the benefit from generated electricity (sensitive analysis under Feed-in-tariff subsidy), and (2) potential benefit (saving of CO_2 emission cost if CO_2 emission tax is applied). It is worth noting that the "Capital Cost" is fixed, one-time expenses incurred from the purchase offshore wind turbines stage until operating status, it is different with "Cost of Capital" (cost of capital is the opportunity cost, and is estimated by Weighted Average Cost of Capital (WACC) method in Section 2.3.3 in this paper).

After the cash flow is obtained, the economic criteria are calculated based on the calculated cash flow and time value of money. Upon the calculated economic criteria, we may assess efficiency of the currently applied subsidies on offshore wind energy, and propose more appropriate subsidies for solving the deficiencies of currently applied subsidies.

2.2. Offshore electricity generation model

The nomenclatures used in this paper are clearly illustrated in Table 1.

In this paper, we compute the electricity generated by offshore wind system based on technical parameters and environmental conditions in twelve investigated regions instead of directly taking data from manufacturers. The technical parameters includes the hub height, efficiency of the gearbox, generator, blade swept area and power coefficient of wind turbines. The environmental conditions include harsh weather conditions (such as typhoon, flood), appropriate weather condition (wind speed is within a range), and unsupported weather condition (such as wind speed is too low or too high). As shown in Fig. 2, the harsh weather condition, proper wind speed and maintenance are checked to calculate the generated electricity. For example: when the wind speed (v) is lower than a cut–in speed ($v < V_L$) or faster than a cut–out speed ($v > V_U$) or when the system is in maintenance period, offshore wind system is deactivated and no electricity is generated in these periods.

Mathematically, the generated electricity (P_{op}) from a wind turbine to feed into the electric grid is a function of the aerodynamic power (P_{pw}), under the efficiency of the gearbox (η_1), generator (η_2), electric (η_3) and the turbine power coefficient (C_P), as is derived by Eq. (1).

$$P_{op} = C_p\eta_1\eta_2\eta_3P_{pw} \tag{1}$$

in which the aerodynamic power (P_{pw}) of an air mass that flows at speed (v) through an blade swept area (A) of wind turbine generator is proportional to the cubed of wind speed, as be shown by Eq. (2).

$$P_{pw} = \frac{1}{2}v_h^3A\rho = \frac{1}{2}v_h^3\pi R(R+2r_h)\frac{\varphi}{GT}^{\frac{-gh}{GT}} \tag{2}$$

Due to the increase in wind speed with altitude, accounting for the effects of wind speed requires knowing the wind turbine hub height (h), and an approximation of surface roughness conditions (z_0). A common approach used for describing the increase in wind speed with the hub height and surface roughness conditions are the logarithmic height formula proposed by [35]. Consequently, the power output from a wind turbine to feed into a grid (generated electricity) is given by: