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Electricity portfolio planning model incorporating renewable energy characteristics

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HIGHLIGHTS

- Traditional electricity planning is only based on the least-cost principle.
- The study incorporates the features of renewable energies into electricity planning.
- Results exhibit that renewable energies can hedge against fossil fuel price risk.
- Results show that the use of renewable energy contributes greatly to reducing CO_2.
- Reflecting the intermittency requires LNG-fired units to serve as backup generators.

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ABSTRACT

Traditional electricity planning models pursue minimal costs, yet their design often results in an underestimation of the true benefits of renewable energy. This paper attempts to introduce different complementary approaches to traditional electricity planning model to incorporate various renewable energy characteristics and uses Taiwan's electricity sector as a case study. The portfolio theory, learning curve theory and the capacity credit are applied in the proposed model to reflect characteristics of renewable energy, such as a hedge against fossil fuel price volatility, significant technological progress, and intermittent generation. Simulation results demonstrate that using renewable energies has the advantage of hedging against the volatile fossil fuel price risk as well as reducing carbon dioxide emissions. Considering the intermittency of renewable energies requires LNG-fired plants to serve as the backup generators. However, wind power can only account for limited share of total installed capacity due to the limited land resources in Taiwan. Therefore, taking intermittency into account only demonstrates a small influence of the reserve margins of the entire power system and the total generation costs.

1. Introduction

The impact of conventional fossil fuels on the environment has led to a search for a reliable and plentiful energy source that creates less pollution while still allowing for continued economic growth. Renewable energy comes from natural sustainable resources and emits a low amount of pollution. Energy diversification decreases dependency on imported fuels [1]; consequently, renewable energy development has become an important focus in countries around the world, including Taiwan [2].

Conventionally, electricity planning is based on least-cost principles, in which systems perform in environments of relative cost certainty, relatively slow technological progress, high availability of homogeneous electricity generating technologies and stable energy prices [3]. However, fossil fuel prices have been fluctuating significantly in recent years. Using a traditional planning model would result in a preference for fossil fuel techniques, thereby overlooking the benefits of renewable energy, including the elimination of price volatility associated with fossil fuels. This approach would be unfavorable for countries that highly depend on imported energy like Taiwan. Recently, rapid technological progress has significantly reduced the cost of renewable energy; consequently, the variable costs and intermittency of this kind of energy lead to increased uncertainty when incorporated into power systems. It is therefore essential to integrate the features of renewable energy into traditional analytical frameworks of electricity planning.

The objective of this paper is to construct an electricity portfolio planning model that incorporates the characteristics of renewable energy. Using Taiwan's electricity sector as a case study, we

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applied portfolio theory, learning curve theory,[1] and the capacity credit[2] to reflect the characteristics of renewable energy, including a hedge against fluctuation in fossil fuel prices, significant technological progress, and intermittent generation. The proposed model was designed to minimize "the present value of total generation costs after risk adjustment" which considers both the present value of total generation costs and the risk (i.e. variance of total generation costs). The model also factors in the constraints of traditional electricity planning models. We then performed simulation analyses and observed the technology portfolios and total generation costs in various scenarios. Finally, suggestions for future policy-making related to the electricity sector are proposed.

The paper is structured into seven sections. The following section begins with a review of relevant literature. Section 3 introduces overview of the current status of Taiwan's electricity sector. Section 4 outlines the structure of the model. Section 5 contains data sources and adjustments. Section 6 presents the simulation results and the final section provides our conclusions.

2. Literature review

Traditional electricity planning models pursue minimal costs, yet their design often results in an underestimation of the true benefits of renewable energy. Researchers in a number of countries, including Japan [3], China [13], Turkey [14], the UK [15], Italy [16], Spain [17], and those of the EU [18,19], have applied portfolio theory to identify the most effective portfolio of power generation technologies. Their results show that traditional models often overlook and are unable to consider the value of renewable energy as a hedge against fossil fuel price risk. In view of this, this paper attempts to combine portfolio theory with traditional electricity planning models to demonstrate the benefits of renewable energy technologies in reducing the generation cost-related risks in the electricity sector.

Researchers in Taiwan primarily employed multi-objective (e.g. the MULTEEE model [20]) or single-objective models (e.g. the MARKAL model [21]) to evaluate renewable energy issues. The objective functions of these models are set for either minimum costs or minimum carbon dioxide emissions (or both). In the selection of electricity generating technologies, there is a lack of consideration for cost-related risks; future fuel costs are assumed to be stable, and the costs of power generation are discounted to obtain levelized costs. For countries which are highly dependent on imported fuel, such as Taiwan, this approach to determine technology portfolios leads to a bias favoring fossil fuels. Furthermore, in technical progress, it is generally assumed that the decrease rates of future costs are exogenously given (for example, the costs decrease by a certain percentage each year) or else the future costs are directly given. Hence, cost reduction caused by the endogenization of technological change is not taken into account. The above are all flaws present in previous electricity planning models. In order to compensate for these shortcomings in existing literature, in this study, we incorporated the features of renewable energy as a hedge against fossil fuel price risk, endogenous technological changes, and the intermittency of power generation. Finally, the model has been applied for the case study of Taiwan's electricity sector. The model is also applicable for other countries, while the necessary data for model calibration are available.

3. Overview of the current status of Taiwan's electricity sector

Table 1 shows the total amount and proportions of electricity generated by Taiwan's electricity sector in 2011. The power supply structure indicates that the overwhelming majority (95.1%) of the electricity in Taiwan is generated using thermal and nuclear energy; renewable energy is responsible for a mere 3.7%. Due to the nuclear-free homeland policy, nuclear waste disposal problems, and concern aroused by the Fukushima nuclear disaster, all nuclear power development, with the exception of the Lungmen Nuclear Power Plant (commonly known as the Fourth Nuclear Power Plant), has been suspended. Nevertheless, the demand for electricity in Taiwan will continue to rise under the economy progresses. As an indigenous energy, the correlation between the price volatility of renewable energy and that of fossil fuels is weak. Therefore, increasing the proportion of renewable energy in the power generation structure can spread the volatility risk of imported fuels and reduce emission of greenhouse gases. In addition, renewable energy technologies, due to their greater potential for cost reductions (higher learning rates), are expected to successfully compete with conventional technologies at some time in the future. However, renewable energies are affected by the time of the day, seasons and weather, and this intermittency will surely affect the continuity and stability of the power supply. Thus, the problem of integrating different features of renewable energies into traditional electricity planning model is crucial. This paper attempts to introduce different complementary approaches to traditional electricity planning model to incorporate various renewable energy characteristics.

4. Model description

4.1. Objective function

In our proposed model, we set the objective function as minimal present value of total generation costs after risk adjustment. In other words, the objective was to minimize both the present value of total generation costs and the risk of total generation costs. Total generation costs include power production costs (fuel costs and variable operation and maintenance costs) and power capacity costs (fixed operation and maintenance costs and capital investment cost). Where the model refers to technical progress it is embodied technical progress, which means the technical progress displayed by newer and more efficient capital performance. Under these circumstances, the capital structure is no longer homogeneous and comprises different vintages. We therefore divided the power generation units by vintage[3] to present embodied technical progress. The development of mathematical models for total generation costs and the risk are outlined in the following.

4.1.1. Present value of total generation costs

The present value of total generation costs (PVTGC) in this model can be expressed as follows.

[1] In energy and climate models, the learning curve has been employed with increasing frequency to account for cost reductions due to technology related learning and for endogenizing technological change [4–12]. In this paper, we used one-way learning curve for renewable energy technologies, in order to take into consideration their greater potential for unit cost reductions and endogenization of technological change.

[2] The capacity credit of that intermittent generation (e.g. wind) means how much of the intermittent generation capacity can be relied on statistically to meet peak demand. That also indicates how much fossil fuel plant can be replaced, while maintaining the same degree of system security, in other words an unchanged probability of failure to meet the reliability criteria for power system. In this paper, we used capacity credit for wind power, in order to take into consideration its contribution to meet peak demand in our long-term electricity planning model.

[3] Vintage refers to the year in which the power generation unit was installed.