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Scenario analysis of the new energy policy for Taiwan's electricity sector until 2025

Fung-Fei Chen [a], Seng-Cho Chou [b,*], Tai-Ken Lu [c]

[a] Taiwan Power Company Research Institute, 198, Roosevelt Road, Section 4, Taipei 100, Taiwan
[b] Department of Information Management, National Taiwan University, 85 Section 4, Roosevelt Road, Taipei 106, Taiwan
[c] Department of Electrical Engineering, National Taiwan Ocean University, No. 2, Pei-Ning Rd., Keelung 202, Taiwan

H I G H L I G H T S

- We constructed three case scenarios based on the Taiwan government's energy policy.
- We employed a long-term Generation Expansion Planning optimization model.
- A significant gap exists between the carbon reduction target and baseline.
- The carbon reduction target requires a holistic resolution needed taking seriously.

A R T I C L E I N F O

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A B S T R A C T

For this study, we constructed the following three case scenarios based on the Taiwanese government's energy policy: a normal scenario, the 2008 "Sustainable Energy Policy Convention" scenario, and the 2011 "New Energy Policy" scenario. We then employed a long-term Generation Expansion Planning (GEP) optimization model to compare the three case scenarios' energy mix for power generation for the next å15 years to further explore their possible impact on the electricity sector. The results provide a reference for forming future energy policies and developing strategic responses.

1. Introduction

Under the cross impact of the greenhouse effect and the environmental and ecological protection in recent years, power utilities worldwide have been working toward developing an environmentally-friendly development framework that considers carbon reduction, efficiency improvement, and energy conservation. The International Energy Agency's "Energy Technology åPerspective" report (IEA, 2010) stated that the optimum strategies to reduce carbon dioxide emissions comprise the following åmeasures: improving end-user energy efficiency (38%), implementing carbon capture technology (19%), developing renewable energy (17%), establishing end-user alternatives (15%), developing nuclear power generation (6%), and enhancing the efficiency of power generation (5%). This indicates that the main source of reducing carbon dioxide emissions is the energy supply side, which accounts for 47%.

In practice, the optimum ratio for the power generation structure must consider numerous factors, including maintaining reserve capacity requirements, ensuring a stable power supply, determining the best ratio of various units, satisfying the power load characteristic, balancing regional supply and demand, reducing pollution emissions from power generation units, maintaining power generation methods, diversifying sources, and safely storing fuel. In addition, Taiwan's power system is independent from other nations' power grids; therefore, Taiwan cannot import electricity from other countries when power shortages occur; however, generating excess electricity is considered a serious waste of precious energy and land resources.[1] Thus, when planning for the proportion of future long-term optimal power generation structure, the power sector must satisfy these requirements and actual situations, as well as consider reducing carbon dioxide emissions. Therefore, the various influencing factors must be considered. In addition, optimal planning of long-term power generation structures and properly configuring resources from the power supply side are important requirements for developing Taiwan's power industry and achieving the carbon dioxide emission reduction targets.

Recently, complying with the government's energy policy has become the biggest variable for the power sector's future long-term Generation Expansion Planning (GEP). The Taiwanese

* Corresponding author. Tel.: +886 2 33661182.
E-mail address: chou@ntu.edu.tw (S.-C. Chou).

[1] In 2011, 99.4% of Taiwan's energy was imported.

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government's 2011 announcement of a new energy policy to reduce the ratio of nuclear power units and expand the ratio of gas-fired units in response to Japan's Fukushima event will significantly impact the power generation structure for the next 15 years. åIn this study, we explore the possible impact of the government's energy policy on the energy sector by using scenario analysis. åIn Section 2, we provide an overview of relevant literature. åIn Section 3, the long-term GEP optimization model is described. In Section 4, the evolution of Taiwan's energy policy and a case simulation analysis of the situation are presented. In Section 5, we analyze the simulation results. Finally, in Section 6, we summarize the results and present our conclusions.

2. Literature overview

Following the recently emerging issues regarding carbon reduction, most energy planning models emphasize the simulation of low-carbon scenarios, especially in European countries. Issues such as analyzing the energy proportion of the electricity sector under CO_2 reduction objectives, increasing renewable energy proportions, improving the efficiency of power generation, adjusting energy prices, and purchasing and selling through the market aim at transforming the current system into that of low-carbon emission energy to determine the optimal solution by conducting various simulation analyses (Nagl et al., 2011). Keles et al. (2011) explored diverse studies regarding scenario simulation analysis of the international energy market in 2010. These studies were classified into three main groups: *moderate*, *climate protection*, and r*esource scarcity and high fossil fuel prices*. Analyzing the German energy market necessitates creating a fourth scenario group that considers the possible revision of the resolved nuclear energy phase out. Obviously, with respect to climate change, the energy conservation requirements, and carbon reduction objectives, exploring a low-carbon energy proportion structure strategy is the primary current concern in the energy market. Scenario analysis is an essential strategic analysis method; various carbon reduction scenarios among countries have resulted in diverse scenario cases for analysis (Keles et al., 2011; Finon and Pignon, 2008; Moreno et al., 2010; Nagl et al., 2011).

In addition to scenario analysis, model application problems are included in the energy planning model. Certain studies have applied inter-industry analysis (i.e., input–output analysis) to analyze the degree of influence that inter-industrial production activities have on each other. The interactive relationship among energy, environment, and economy (3E) is investigated to estimate the CO_2 emissions of different industrial sectors (Kim, 1998; Chang, 2008; Chung et al., 2009). Additional studies have established multiple objective programming, which is a mathematical programming model that considers multiple decision objectives in the decision procedure; these studies have explored accommodation relationships for conflicts that exist among objectives (Heinrich et al., 2007; Chang, 2008). Therefore, when different models are used, the main consideration is the size set of the simulation analysis scope. Inter-industry analysis is a preferable model for examining 3E, whereas multiple objective programming is used to determine the solutions and accommodations for different objectives. Other studies have adopted hybrid models, such as combining inter-industry analysis and multiple objective programming to determine the simulation analysis solution (Chang, 2008).

Furthermore, to determine the solution of the optimization model, a linear planning theory model is commonly used. The electricity industry exhibited a liberal trend in the 1980s and 1990s, when numerous algorithms were used in the field of electrical energy planning. He and David (1995) proposed the global optimization of long-term power supply planning. Kannan et al. (2007) organized related theories and determined six long-term power supply planning algorithms by conducting experiments. The six algorithms include differential evolution (DE), evolutionary programming (EP), simulated annealing (SA), evolutionary strategy (ES), hybrid approach (HA), and dynamic programming (DP), and are used to determine the optimization algorithm of solutions. Mixed-integer linear programming (MILP) is a derivative of linear programming applications that is used to determine the solution of linear programming models comprising variable types of general and integer variables. When long-term power supply planning uses a generator set as the unit of analysis, the optimization model related to generating the capacity planning of generator sets is fairly complicated. The model must consider the generating capacity and state characteristics of the sets. Commonly, binary integer variables with values of 0 and 1 are used to indicate whether the set is in operation. Therefore, using MILP in the optimization model that uses sets as the unit of analysis is appropriate (Yong and Shahidehpour, 2007; Li et al., 2007; Aminifar et al., 2009).

The energy planning model includes a discussion of power generating technologies. Previous studies have explored cost structures of generating technologies. Fritsche (2006) analyzed the generating costs of the German electricity sector, where coal-fired cogeneration and photovoltaics had the lowest and highest generating cost, respectively. This showed that different generator set structures also influenced the total generating cost. In addition, developing advanced generating technologies, including IGCC, CCS, and fuel cells, can significantly influence the carbon reduction effect of electricity sectors. However, according to the “Energy Technology Perspective, Scenarios and Strategies to 2050” by IEA (2006), the majority of the advanced technologies that can effectively eliminate CO_2 emissions from fossil fuel generation will not be effective until difficulties in technologies, costs, and other dimensions are solved by 2030.

In summary, the established optimization energy planning model, which uses generator sets as the unit of analysis, focuses on the analysis of energy proportion variations among different case scenarios based on the Taiwanese power system. Thus, we adopted a mixed integer linear programming (MILP) model to solve the GEP problem, the details are shown in Section 3. The model compared and analyzed the energy proportion variations among various case scenarios to provide a reference for energy policy makers and electricity sectors to develop corresponding policies and strategies.

3. Optimization model

The primary objective of long-term generation expansion planning (GEP) is to formulate the most efficient power supply arrangements that satisfy long-term load demands by examining factors that include the following: government laws and regulations, international energy prices, the greenhouse effect, power generation technology, and operating environments. For example, advanced generators can be used as standby generator sets for GEP, and long-term load forecast software can be employed to formulate programs to address long-term load demands by considering factors such as economic development, demand management, and power efficiency. In addition, international energy prices can be estimated using energy price forecast software.

This study adopted a mixed integer linear programming (MILP) model to solve the GEP problem; its objective function and significant constraints are explained below. The brief description of the long-term GEP optimization model is shown in Appendix A.

3.1. Objective function

The objective function is the fuel costs of all the units during the planning period, including changes in operation and maintenance costs, carbon taxes, and fixed operation and maintenance costs.