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Multi-choice goal programming model for the optimal location of renewable energy facilities

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ABSTRACT

This paper proposes a multi-choice goal programming model for dealing with the capacity expansion planning problem of the renewable energy industry. This model involves decisions regarding the optimal mix of different plant types, location selection and other criteria. Different types of plants should be located in appropriate places so as to minimize the total deviations from predefined goals concerning power generated, investment cost, emission avoided, jobs created, operation and maintenance costs, distance security, and social acceptance. The proposed method is superior to the goal programming model proposed by Ramón and Cristóbal, in that it can avoid underestimation of aspiration level, expand the potential feasible region, and achieve findings more closely approach actual conditions. In addition, the social acceptance of the renewable energy planning problem in Taiwan is modeled by the MCGP to demonstrate its usefulness.

Contents

1. Introduction

Because of continuous economic growth and industrialization worldwide and the soaring energy demands in the five major developing countries of Asia (China, India, Indonesia, Korea and Thailand), the demands on fossil energy for industry, transportation and daily life are becoming increasingly large. Table 1 shows the global reserves and the projected number of years of supply remaining for major fossil fuels [1,2]. Even with recent discoveries of new reserves, such as shale gas, tight sands and shale oil in North America, as well as shale oil in many other areas, fossil fuels are gradually being depleted. International oil and coal prices exceeded US $102 per barrel and US $75 per ton in April 2010 [3,4]. Since Taiwan has almost no energy resources, 97.92% of the total energy requirement depended on imports in 2013 and almost all of the fossil fuel is imported from politically unstable areas, such as the Middle East, so Taiwan's energy security has become increasingly vulnerable. Energy imports also increased from 3.88% of Taiwan's GDP in 2002 to 14.55% in 2012, which creates a large drain on Taiwan's economy. In addition, traditional uses of fossil fuels aggravate environmental pollution and the greenhouse effect. Thus, the development of renewable energy is an increasingly important issue for both developing and developed countries.

Taiwan's energy supply and consumption in 2012 are listed in Fig. 1. Compared with 2011, petroleum is 3.4% higher, renewables are 0.1% higher, nuclear is 0.2% higher, natural gas is 0.7% higher, and coal is 4% lower. This means that Taiwan is gradually improving with the use of cleaner fuels to reduce carbon emission from power generation. Since the 2011 nuclear disaster at Fukushima, the

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Table 1
Global reserves and availability of major energy resources.

Category item	Oil (+oil sanss)	Natural gas	Coal
Total reserves (end of 2011)	1481 billion barrels	196 trillion cubic meters	860 billion tons
Yield (2011)	30 billion barrels	3.2 trillion cubic meters	6.7 billion tons
Available years	49 years	61 years	112 years

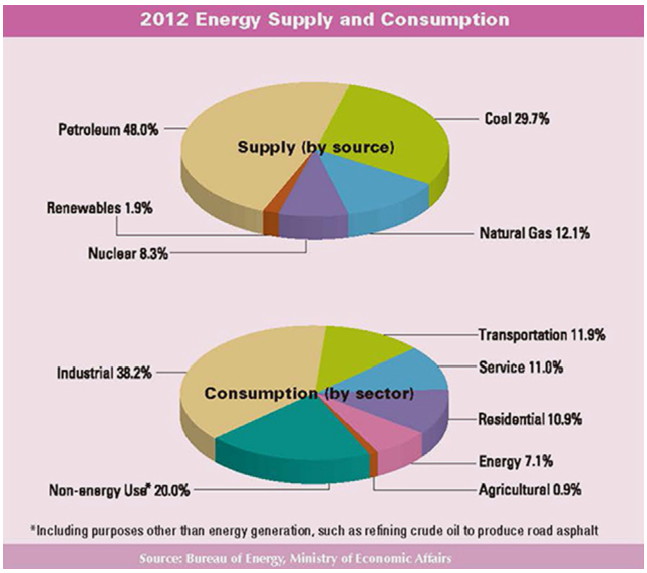

Fig. 1. 2012 Energy supply and consumption in Taiwan.

government of Taiwan has considered a nuclear energy reduction policy. Overall, it is a top priority of Taiwan to develop clean, sustainable, and independent energy and achieve a balance between energy security, environmental protection, industrial competitiveness, and economic development. This is particularly important for Taiwan's environment, with the sunny weather in southern Taiwan and abundant wind resources on the west coast of Taiwan. These issues lead to both crisis and opportunity for Taiwan in becoming a sustainable community. In order to encourage the development of renewable energy, the National Science Committee (NSC) initiated the flagship project “New Projects of Energy Technology” in 2008. Subsequently, the Ministry of Economic Affairs (MOEA) promulgated the “Renewable Energy Development Act (REDA)” in 2009, the “Incentive Program of Offshore Wind Power Demonstration System” in 2012, the “Million Solar Rooftop Photovoltaic Program” in 2013, and the “Small Wind Turbine Generation System Demonstration Incentives” in 2014. Many kinds of financial compensation are offered by the central and local governments. Further programs are also expected under the Bureau of Energy (BOE) for promoting renewable energy usage: (i) Total renewable energy capacity of 9952 MW in 2025 (i.e., 15.5% of the total power generation installation capacity in Taiwan); (ii) 1000 on- and off-shore wind turbines, with the wind power capacity of 4200 MW in 2030 and progress on the construction of the wind power system as shown in Table 2; and (iii) the “Million Solar Rooftop Photovoltaic Program” project, with photovoltaic power capacity of 3100 MW in 2030. In particular, the Industrial Technology Research Institute (ITRI), Taiwan Power Company, Chinese Petroleum Corporation, and others have begun to carry out research on renewable energy technology. From the promulgation of the REDA in 2009 to the end of 2012, the capacity of photovoltaic power increased from 11 MW to 222.4 MW, the capacity of wind power increased from 436 MW to 621 MW.

However, these infrastructure projects are often contested and face public resistance, in particular against many of the on-shore wind power projects in Taiwan. Therefore, public resistance should be considered as an important factor in a model for the optimal location of renewable energy facilities. The capacity expansion planning problem of the renewable energy industry should not only to determine the best renewable energy project among different alternatives, but also develop expansion plans for energy generation, transmission and distribution systems with consideration of the potential public resistance to these projects. This problem involves important decisions regarding the optimal solutions of different plant types, locations, and capacities. A variety of approaches have been employed to model the generation and distribution of electricity, such as of multi-criteria decision-making models [5–7], optimization models with geographic information systems for regional renewable energy development [8], and goal programming (**GP**) model for the optimal mix and location of renewable energy plants [9]. As a result, multi-criteria decision-making methods such as the Analytical Hierarchy Process (AHP), Elimination and Choice Expressing Reality (ELECTRE), Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE), Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS), and VIšekriterijumsko KOmpromisno Rangiranje (VIKOR) have been extensively adopted for the selection of renewable energy problems such as wind-farm projects, geothermal projects and hydro-site selection [10–16].

Though these methods have been widely applied to the renewable energy industry, the multi-choice goal programming (**MCGP**) method [17–19] has rarely been used for the location selection problem of renewable energy plants and capacity expression decisions. MCGP is a multi-choice aspiration-level approach which has been applied to many real-world problems, such as housing selection [20], low-cost carriers' networks [21], supplier selection [22,23], forestry plans [24], forestry management [25] and a piloted quality-management system [26]. Moreover, using MCGP to deal with the optimal location of renewable energy plants, can provide the following advantages:

- MCGP expands the original feasible region (it may be obtained using Weight GP, MINMAX GP, or Lexicographic GP) to the potential feasible region for obtaining the appropriate solution for decision-makers (**DMs**) responsible for the selection of the renewable energy plant location [17].
- It not only can deal with quantitative issues (e.g., minimization of operation and maintenance costs) but also qualitative problems (e.g., maximization of user satisfaction and social acceptance) [17].
- It allows DMs to set multiple aspiration levels to avoid underestimating settings determined by conservative chief-executive officers. For example, the lower power capacity of 113,609,530 W is obtained in the model of Ramón and Cristóbal (**RC**) [9] because the power generation goal (110×10^6 W) is underestimated in their model. In contrast, a higher power capacity of 116,587,600 W is obtained by the MCGP model because MCGP can reflect higher aspirations. That is, by