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Optimization of China's energy structure based on portfolio theory

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ABSTRACT

Facing the mounting pressures of meeting energy and environment needs and reducing its dependence for fossil fuels, China needs to make more effort to develop renewable energy. This paper attempts to use portfolio theory to optimize China's overall energy system with considering the learning curve effect of renewable energy cost and the characteristic of fossil energy cost increasing over time. It also takes into account additional factors such as environmental costs of coal consumption and various growth rates of the cumulative R&D (research and development) capacity for solar power. This research has found that the development of renewable energy in China has tremendous potential but it will not replace fossil energy in the next decades. The sensitivity analysis of this paper indicates that development of solar power is driven not only by the cumulative installed capacity but also by the cumulative R&D capacity.

1. Introduction

Energy is the important material foundation for human's survival, economic development and the social progress [1]. While China has experienced great success in economic and social development, however, its energy development confronts many problems that urgently need to be addressed [2,3]. On the one hand, China's primary energy consumption in 2012 was 3.48 billion tons of standard coal equivalents [4]. Constrained by the country's current energy structure, coal accounts for 68.5% of China's total energy use while oil accounts for 17.7% [4]. Using of renewable energy resources such as solar and wind power has accounts for less than 1.2% of China's total energy consumption [5]. Fig. 1 depicts the fuel structure of China's energy use in 2012. On the other hand, the demand for oil in China has growed rapidly. Because domestic oil production is shortage, China's dependence of crude oil imports jumped from 31% in 2001 to 58.3% in 2012 [6], it makes China the biggest oil importer in the world. In conclusion, China's current energy system is dominated primarily by fossil energy and the share of renewable energy is still trivially compared to the country's resource potential. Therefore, there is room for China to improve its energy efficiency, especially western provinces which have large amount of energy input excess [7] and the inappropriate energy consumption structure should be changed as China's domestic renewable energy sources are abundant and show the possibility to cover future energy demand [8].

Research on the optimization of energy structure has an important significance for improving China's energy structure. First, energy structure optimization is not only the crucial content of the sustainable energy strategy, but also the vital guarantee of sustainable economic and social development. Second, energy structure optimization is the fundamental mean to enable China to achieve its ambitious goals of energy, environmental, and climate. To address the energy and environmental problems confronted by China, the country needs to improve its current energy structure by increasing the share of renewable energy and diversifying its energy supply. For example, Wang Feng [9] predicted the trend of China's carbon intensity during the period 2011 to 2020 using integration technology and Markov chain model, and then assessed the contribution of improving energy mix to carbon intensity target in nine scenarios. He concluded that: In the scenario that economy grows at a high speed, carbon intensity would decrease by 19% which would make 42.3%–47.6% of contribution to the achievement of the carbon intensity target. Wang Shaohua [10] analyzed primary energy consumption change and carbon emission intensity, by defining the relationship between primary energy consumption and its direct and indirect influence on carbon intensity. The result showed that optimizing the primary energy

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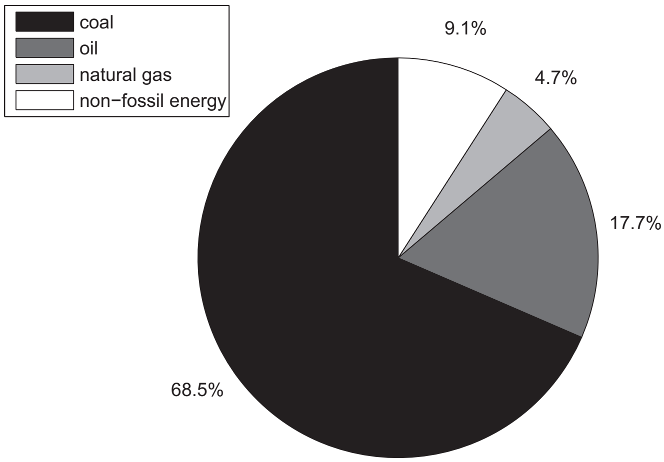

Fig. 1. The fuel structure of China's energy use in 2012.

consumption structure can lower carbon intensity by 4.6%, and contribute 26.9% to achieving the carbon intensity target in the 12th Five-Year Plan. Tianyu Qi [11] found that current renewable electricity targets result in significant additional renewable energy installation and a reduction in cumulative CO_2 emissions of 1.8% relative to a No Policy baseline during the period from 2010 to 2020. And after 2020, the role of renewable is sensitive to both economic growth and technology cost assumptions.

With regard to the optimization of energy structure, there are different techniques which will have different effects on the optimization result. Banos et al. [12] provided an overview of the latest research developments concerning to the use of optimization algorithms for design, planning and control problems in the field of renewable and sustainable energy. Liu et al. [13] established a mathematical model of dynamic energy system based on superior control theories, and analyzed the superior strategy for the replacement of renewable energy on fossil energy. Huva et al. [14] presented results from a prototype renewable energy network optimization model, and estimated potential power output for various combinations of wind and solar farms across a large domain of several hundred kilometers and calculated the required back-up power capacity needed to meet demand. Motaz Amer [15] presented a method for the optimization of the power generated from a Hybrid Renewable Energy Systems in order to achieve the load of typical house as example of load demand. Rong-Gang Cong [16] developed the renewable energy optimization model and analyzed the development of three renewable energy resources (wind power, solar power and biomass power) from 2009 to 2020 combined with the learning curve model, the technology diffusion model and expectations about future economic development in China. Mondal et al. [17] presented an evaluation of future energy-supply strategies for the United Arab Emirates power sector and identified the prospects for the further economic development of the country while addressing energy security issues and mitigating environmental impacts. Yong Ping Li [18] developed an integrated optimization modeling approach for planning CO_2 abatement through emission trading scheme and clean development mechanism and applied the model to a case study of planning CO_2 emission mitigation for an electric-power system that involves three fossil-fueled power plants (i.e., gas, oil and coal-power plants). The results demonstrated that CO_2 emission reduction program can be performed cost-effective through emission trading and clean-energy development projects.

The review of previous studies has shown that most existing researches focused on the optimization of energy structure. This paper applies portfolio theory to optimize China's overall energy structure. Compared with previous studies, this paper gives the optimization of China's future energy mix in the next two decades for different levels of risks and expected returns. Optimal portfolio selection is generally based on mean-variance portfolio theory developed by Harry Markowitz in 1952 [19]. It enables the creation of minimum-variance portfolios for any given level of expected (mean) return, and researchers around the world started to apply portfolio theory to the study of the optimization of energy structure. The nature of investment portfolio is to select an optimal combination from uncertain risks and returns. Therefore, choosing the appropriate way to determine the portfolio returns and risks is the key to solving the problem of optimizing the energy structure.

In this paper, the expected return is set to the inverse of cost. In order to make the unit consistent, we use the thermal cost in Chinese Yuan/Joule. For fossil energy, we use their prices and the corresponding calorific values to calculate their thermal costs. The prices of oil and natural gas are taken from domestic prices in 2012 with considering the average rates shown in BP Statistical Review of World Energy 2012 [20]. The price of coal is forecasted based on the average coal price between 2000 and 2012 in a China's typical coal-fired power plant. The costs of hydro and nuclear power are obtained from the result in Zhu and Fan [21] with considering the limitation of data availability. For renewable energy excluding hydro power, their production costs are calculated by using the learning curve approach and then converted to thermal costs. Current literatures usually define the risk as the fluctuation of the cost or price. In this paper, the definition of risk is divided in two categories. For fossil energy, the risk is defined by the price volatility. However, for new energy and renewable energy, the definition of risk is their feed-in volatility.

The structure of other sections for this paper is as follows. Section 2 describes the portfolio theory model, and calculates the expected returns and risks for various energy resources. Section 3 examines the impacts on China's future energy structure optimization under different scenarios with assuming a 25% of average growth rate for cumulative solar energy cumulative R&D (research and development) capacity which derives from historical information in combination with the environmental costs of coal. Section 4 is the sensitivity analysis and compares the possible impact when increases average growth rate for solar energy cumulative R&D capacity to 35% with considering the environmental cost of coal use. Section 5 presents major conclusions of the paper and points out the areas that need further research.

2. Methodology

2.1. Model description

Harry Markowitz, an American economist, pioneered the work in modern portfolio theory and conducted influential research on this subject [19]. The nature of investment is to choose the optimized combination between the probabilistic profit and the risk, and the so-called optimized combination is to find a portfolio that gives maximum return for a given risk, or minimum risk for a given return. And the best of all combinations becomes the efficient frontier. Brodie et al. [22] considered the problem of portfolio selection within the classical Markowitz mean-variance framework. According to Brodie et al., “the penalty regularizes the optimization problem, encourages sparse portfolios, and allows accounting for transaction costs.” In order to use portfolio theory effectively, we make three assumptions: First, to assess the stand or fall of portfolio mix, two indicators, expected return and risk are considered; Second, it is a frictionless energy market, namely neglecting taxes and transaction fees; Third, the domestic economy will keep