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Renewable energy investment risk evaluation model based on system dynamics

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ABSTRACT

China currently faces the dual constraints of developing low-carbon economy and enabling sustainable energy utilization. It is an inevitable choice for the strategic transformation of economy development and energy development in China to develop renewable energy. Since renewable energy is a capital-and tech-intensive industry, which requires a large amount of investment and a high level of technology innovation. Investors face many different uncertainties when making a renewable energy project investment decision. Therefore, it has great significance for the development of renewable energy to evaluate the risks in renewable energy investment projects, and then make the best investment decisions. Based on above background, the topic of renewable energy investment risk is studied in this paper using system dynamics method. In the first part of the work, three main risks in renewable energy investment, technical risk, policy risk and market risk, have been discussed, and then causal loop diagram of investment risk and risk assessment model have been established by the system dynamics method, after that a numerical example was given in the last part of the paper. The result of the numerical example indicated that policy risk was the main factor affecting the investment in the early development stage, while policy risk and technology risk decline gradually, market risk has gradually become the main uncertainty affecting the investment in the mature development stage.

1. Introduction

Along with the continuous development of economy and society, China's energy demand continues to grow rapidly. Energy and environment problems have become increasingly prominent, which signify that accelerating the development and utilization of renewable energy has become the only way to response the serious energy and environment crisis [1]. Prompted by “Renewable Energy Law” and related policies, renewable energy has developed rapidly in China. Wind energy is now entering large-scale development stage, and solar energy is rapidly developing. The scale of renewable energy industry is expanding with continuous technology advancement. By 2013, the installed capacity of renewable energy comes to 380 million kW, and an increase of 18% compared with 2012, accounting for 30% of total installed capacity [2]. China's renewable energy generating capacity reached 1 trillion kW·h in 2013, accounting for about 20% of the national electricity generation [3]. At present, more and more investors begin to invest in renewable energy projects, while uncertainties in investments have become increasingly prominent [4]. These uncertainties caused by complex investment environment could bring failure in to the renewable energy projects. Therefore, in order to ensure a reasonable return on investment, it is necessary to identify various kinds of risks in renewable energy investment activities. The basic task of risk identification is to identify and understand the types of risk, as well as the possible serious consequences. Without risk identification, it is impossible to know what type of risk exists, what would happen during the process of projects implementation, and may lose the opportunity to control or address these risks timely and effectively Table 1.

In order to identify the risks in renewable energy investment, scholars have made a lot of research work, of which focused on risk source, assessment and response of renewable energy investments [5–9]. Research on risk sources indicate that policy risk, technology risk, economic risk, security risk and other related factors exist in renewable energy investment. Risk evaluation of wind power project was studied in Literature [10], investment risk evaluation index system based on Life Cycle Theory, as well as TOPSIS evaluation model based on Gray Relation Grade, has been constructed, the author also examined the rationality and feasibility of the model through a numerical example. Decision variable of business risk is analyzed based on beta model in

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Table 1
Incentives policy in different development stages of renewable energy.

Development stage	Policy objective	Institutional incentive policies	Fiscal and taxation incentive policies	Investment and financing incentive policies
Research and development stage	Support	Renewable Energy Law; Strategic development planning; Technology Development Plan.	National special subsidies; Set up special research and development fund; Accelerated depreciation; Investment credit policy; Income tax relief; financial discount policy; Financial subsidies to producers; Government procurement policy;	Policy loans; Preferential commercial loan; Policy investment.
Primary development stage	Support	Feed-in tariff policy; Bidding system; Gradual introduction of the quota system; Gradual introduction of green certificate transactions.	Fiscal subsidies; Technology and equipment tariff reduction; Tax reduction policy;	Policy loans; Preferential policies of the commercial loan; Policy investment; Securities or equity financing; Issue bonds.
Large-scale development stage	Support	Part of the implementation of feed-in tariff policy and competitive-bidding system; Implementation of quota system and green certificate transactions; Gradual introduction of fair competition in energy market.	Gradual reduction of financial subsidies and tax incentives.	Gradual elimination of Gradually policy-related loan, preferential policies of the commercial loan, policy investment, securities or equity financing, and issue bonds.
Mature stage	Regulate	Gradual elimination of bidding and quota system; Implementation of fair competition in the energy market.	Marketization	Marketization

Literature [11]. Literature [12] used a multiple risk factors method to quantify market risk of wind power. Literature [13] used NPV and Monte Carlo Simulation to calculate the risk of renewable energy investments. Integrating a variety of risk assessment methods, Relative difference degree of fuzzy risk assessment model based on interval variable weight was established in Literature [14], and the wind power project in Inner Mongolia has been taken as an example to verify the practicability of this model.

From the literature analysis on investment risk of renewable energy, it is known that some shortcomings were existed in traditional risk analysis methods. First, the traditional risk analysis methods don't consider the dynamically change of risks in the whole project cycle and the influence on the system risk affected by feedback loops. Secondly, the interaction among different risks is not considered in traditional risk analysis method. Finally, the traditional risk management methods are mostly based on qualitative analysis and research. Based on the analysis above, System Dynamics Theory will be introduced to establish renewable energy investment risk model in this paper. Then, taking a wind power project for example, the investment risks of the project were identified and evaluated with VENSIM software. System Dynamics model constructed in this paper can help investors to evaluate risks in the early stage of the project, as well as to provide decision-making reference for investors and governments.

The paper is arranged in the following way: in Section 2 methodology used in the paper is introduced. Section 3 presents the renewable energy investment risk model structure and its general description based on System Dynamics Model. Section 4 introduces the case analysis. Section 6 discusses the major conclusions.

2. Methodology

2.1. System dynamics theory

System Dynamics is a subject about information feedback proposed by MIT's famous professor Jay W Forrester in the 1960s. It is an analysis method of combining qualitative analysis, quantitative analysis and synthesis reasoning, which is regarded as an effective approaches and methods for nonlinear complex systems and scientific decision-making. System dynamics is a methodology for studying and managing complex feedback systems, such as one finds in business and other social systems. In fact it has been used to address practically every sort of feedback system. While the word system has been applied to all sorts of situations, feedback is the differentiating descriptor here. Feedback refers to the situation of A affecting B and B in turn affecting A perhaps through a chain of causes and effects. One cannot study the link between A and B and, independently, the link between B and A and predict how the system will behave. So, if we want to get the correct results, the only way is study of the whole system as a feedback system.

System dynamics modeling is useful for understanding the underlying behavior of complex systems over time, taking into account time delays and feedback loops [15]. The dynamic relationship among the structure, function and behavior could be studied through the establishment of the system dynamics model, using DYNAMO simulation language or VENSIM software.

2.2. System dynamics used in renewable energy investment risk analysis

The complexity and dynamics of renewable energy investment risk make accurate risk evaluation difficult if using a simple static model or a comprehensive evaluation method, while System dynamics is an approach to understanding the behavior of complex systems over time, which meet the requirements of risk assessment for renewable energy investment. It deals with internal feedback loops and time delays that affect the behavior of the entire system. What makes using system dynamics different from other approaches to studying complex systems is the use of feedback loops and stocks and flows. These elements help describe how even