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Comprehensive assessment of flexibility of the wind power industry chain

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ABSTRACT

A number of energy development plans have been released in China in recent decades. These plans were aimed at promoting the optimization of the Chinese energy industry structure and achieving emission reduction targets by encouraging the development of clean energies such as wind energy. The sustainable development of the clean energy industry chain faces a number of challenges, one of which is the lack of flexibility. This has led to some serious issues associated with clean power industries such as wind power and it is timely to investigate the flexibility of the wind power industry chain to ensure its sustainable development. A hybrid research methodology has been employed in this study to identify most critical factors that affect the flexibility level of the wind power industry chain. These factors are related to seven types of flexibility, i.e. structural flexibility, production flexibility, operational flexibility, technological flexibility, development flexibility, construction flexibility, and policy flexibility. A flexibility assessment index system classified according to upstream, midstream and downstream industry supply chain has been established for the wind power industry chain and a Matter-element extension model was adopted to determine the level of flexibility. The flexibility deviation of the main factors that affect the flexibility of wind power was calculated using sensitivity analysis. The case study suggested that it is feasible to utilize this novel method to evaluate the flexibility of the wind power industry chain. The outcomes of the flexibility analysis provide useful information to assist the decision making process of both government and industry.

1. Introduction

With abundant wind resources, the wind power industry in China has achieved rapid growth during the last two decades. The total installed capacity of wind power in China reached 75.32 GW by the end of 2012, placing it first in the world at that time. In 2012, 12.96 GW were added to the grid-connected capacity increasing its total to 62.37 GW [1].

The wind power industry is also facing some significant challenges, e.g. the official statistics from the National Energy Administration, place the national average utilized hours of wind energy at 1890 in 2012, i.e. 30 h less than the previous year [2]. In some regions, this figure fell as low as 1400 h. This has become a serious issue in these regions where wind power has either been abandoned or been restricted in use.

A number of similar issues exist in various segments of the industry chain of China's wind power sector. As shown in Fig. 1, the entire industry chain consists of three segments, i.e. upstream, midstream and downstream. For the upstream segment, the domestic wind power manufacturers have used mature technologies employing wind turbine units under 2 MW. However, the production and assembly of the large-scale and high-capacity wind power turbines still rely on foreign manufacturers and there is a large gap between domestic and foreign manufacturers in terms of technological innovation and resource integration. In the midstream industry segment, the vast majority of wind farms are owned and operated by five power generation groups, i.e. the China Huaneng Group, the China Datang Group, the China Huadian Group, the China Guodian Group and the China Power Investment Corporation. There has been a tendency for large-scale wind power development in recent times [3], however, it is not unusual for the installed capacity of wind farms to be somewhat varied, due primarily to the lack of

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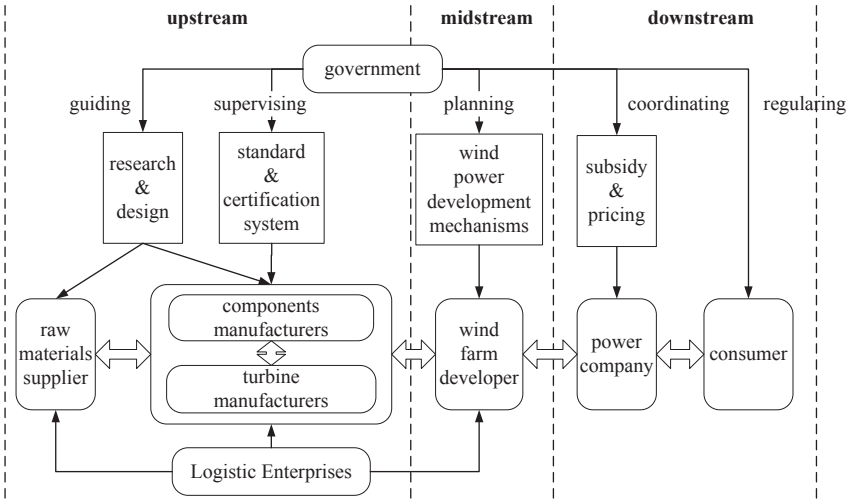

Fig. 1. The structure of China's wind power industry chain.

sophisticated investigation of the local consumption capacity during the feasibility study. As a result, newly built wind farms are not able to generate full power load due to the issues associated with grid connection and load restrictions. This has led to significant losses for wind farm developers and operators.

The downstream industry segment generally consists of power companies. The unstable characteristics of wind power (due mainly to the amount of wind available) present significant challenges when connecting wind energy to the power grid. This instability requires the company to construct infrastructure to accommodate fluctuating wind loads. The infrastructure must accommodate grid connection, and wind power storage. Similarly, the whole industry chain is affected by government policies that require improvement at the institutional level of the wind power industry. This presents a major barrier to the sustainable development of the wind power industry.

Based on existing studies [4–6], a definition of the flexibility of an industry chain is proposed in this paper: the "Flexibility" is *a comprehensive capacity of the industry chain to identify and to respond to the dynamics of internal and external environment*. This capacity helps to adapt the overall operation of the industry chain to the changing environment. Indeed, both internal environment (e.g. strategy, research and development, resource, investment, production, and operation) and external environment (e.g. supply and demand, market competition, laws, regulations and policies, cooperation between related sectors) affect the sustainable development of the wind power industry. Thus, it is imperative to explore how the wind power industry adapts to the external environment as this will help each component of the industry chain to achieve a realistic level of flexibility.

There are very few studies dealing with the flexibility of the wind power industry chain and the majority of these studies focus on risk management, the operation of the wind power industry and the relevant assessment models. For instance, there are four stages of the industry chain risk management process, i.e. identifying risks, determining the management strategies and actions, implementing actions and monitoring and results analysis [7]. Gouveia and Matos analyzed the volatility and uncertainty risks of wind power turbine by using the multi-level Markov model [8]. Based on the literature survey and the empirical study, Craighead et al. assessed the impacts of a variety of disturbances to the industry chain; and subsequently proposed a series of risk control strategies to enhance both risk resilience and early warning capabilities [9]. From the industry management perspective, Martins et al. introduced the public–private partnership model to wind farm development and construction [10]. The wind power industry can learn from management and operation practices in other sectors in order to improve the level of flexibility. Similarly, international cooperation plays a critical role in renewable energy development in China, providing useful inputs to the government's policy making process [11]. Focusing on administrative procedure, Zhao and Chang investigated ways to develop stable and profitable wind farms from the regulatory perspective [12]. One of the effective approaches to managing risk for industry chains is to reduce transaction cost by promoting a more collaborative relationship between enterprises in the industry chain thereby enhancing information sharing and trust [13,14]. Wu et al. compared three industry chain risk assessment models, i.e. chance constrained programming (CCP), data envelope analysis (DEA) and multiple objective programming (MOP) through multiple case studies [15] thereby providing a benchmark for the assessment of the wind power industry chain flexibility.

It is well recognized that the wind power industry chain is complex due to the turbulent environment. However, previous studies did not explore the wind power industry from a novel view of flexibility with a consideration of the changing environment. Similarly, the operation mechanisms, dynamic development and competitiveness characteristics of the wind power industry were not examined under an overall industry chain model. To achieve the sustainable development, efforts are required to improve the level of flexibility of the wind power industry chain so that the adaptability can be adjusted and strengthened accordingly. Therefore, this study focuses on the flexibility assessment of the wind power industry chain. Factors influencing the flexibility of the wind power industry chain are drawn from industrial review reports, policy analysis, literature surveys, expert interviews and questionnaire surveys. The Matter-element extension model is used to establish the flexibility assessment system and this is tested in a case study that reflects the issues associated with the regional wind power industry. Sensitivity analysis is then used to determine the flexibility deviation of the main factors.

2. Research methodology

This study analyses the official report of the wind power industry chain, the wind power policies and other related literature to