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Efficiency assessment of hydroelectric power plants in Canada: A multi criteria decision making approach

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ABSTRACT

Hydropower plays a major role in the Canadian electricity generation industry. Few attempts have been made, however, to assess the efficiency of hydropower generation in Canada. This paper analyzes the overall efficiency of hydropower generation in Canada from comprehensive viewpoints of electricity generating capability, its profitability, as well as environmental benefits and social responsibility using the TOPSIS (the Technique for Order Preference by Similarity to Ideal Solution) method. The factors that influence the efficiency of the hydropower generation are also presented to help to the sustainable hydropower production in Canada. The most important results of this study concern (1) the pivotal roles of energy saving and of the social responsibility in the overall efficiency of hydropower corporates and (2) the lower hydropower generation efficiency of some of the most important economic regions in Canada. Other results reveal that the overall efficiency of hydropower generation in Canada experienced an improvement in 2012, following a downtrend from 2005 to 2011. Amidst these influencing factors, energy saving and social responsibility are key factors in the overall efficiency scores while management (defined herein by the number of employees and hydropower stations of a corporation) has only a slightly negative impact on the overall efficiency score.

1. Introduction

Renewable energy development plays a significant role in meeting energy demand, boosting energy security, addressing environmental issues and climate change as well as contributing to other aspects of social development (Flavin and Aeck, 2005; IEA, 2012). Total renewable power capacity worldwide exceeded 1470 GW in 2012, up by 8.5% from 2011 (REN21, 2013). Out of this, renewable power capacity additions represented more than one third of global power capacity developments (GEA, 2012). Furthermore, hydropower rose worldwide by 3% to an estimated total installed power of 990 GW in 2012, accounting for 67% of renewable energy capacity. That is to suggest that among renewable resources, hydropower occupies the dominant role in renewable energy market and leads the way for reliable, renewable and clean energy.

Hydropower plays a vital role in meeting Canada's growing electricity needs while reducing air pollutants and greenhouse gas emissions (Canadian Hydropower Association, 2008). While Canada's energy sector is the fourth largest contributor to Canada's GDP, Canada is the world's third largest hydropower generating country. And hydropower, as the largest primary source in 2012, accounted for 63.3% of the total electricity generation and totaled 376.4 million megawatt-hours in Canada. Furthermore, numerous provinces greatly depend on the use of hydropower for electricity, including Quebec (QC), Manitoba (MB), British Columbia (BC), Newfoundland and Labrador (NL) and Ontario (ON). Moreover, over 90% of the electricity consumed in the provinces of Quebec, British Columbia, Newfoundland and Labrador, Manitoba as well as in the Yukon Territory is from hydropower (Canadian Electricity Association, 2013a).

The significance of hydroelectric power in Canadian power generation industry shows that efficiency analysis is essential to the management of hydropower generation in Canada. This topic has received worldwide attention. However, few attempts have been made to analyze the efficiency of hydropower generation in Canada. Moeini and Afshar (2011) presented ant colony optimization algorithms to hydropower reservoir operation problems in Canada and concluded that this model is useful for optimal

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operation of hydropower reservoirs. Minville et al. (2009) combined the regional climate model with statistical tests to evaluate the impacts of climate change on hydropower production and power plant efficiency and further projected the trends of hydropower production from 2010 to 2099. Their hydropower generation efficiency analysis mainly considered technological efficiency by using a case study. With the increasing concern about environmental issues and corporate social responsibility, a comprehensive framework for hydropower efficiency analysis is needed. Furthermore, the efficiency of hydropower generation only at one plant or a river basin is not representative for the efficiency at regional level.

In the absence of research work about the efficiency of hydropower in Canada, the present study is a timely role and expands the research breadth in this field from more sustainable and responsible perspectives. This study applies the decision method to deduce the overall efficiency of hydropower generation in Canada and analyzes the impact factors of hydropower efficiency through the use of a regression model. Benchmarking management is further employed to identify best practices and suggests improvements for the hydropower production sector in Canada. This decision analysis is performed by employing the general version of TOPSIS (the Technique for Order Preference by Similarity to Ideal Solution). Considering the lack of a comprehensive study on the overall efficiency of hydropower generation and that few studies have been conducted to investigate this topic from the aspects of climate change, other environmental aspects and corporate social responsibility, this paper attempts to address three issues:

(1) When considering the technical, environmental and social aspects of hydropower generation, what is the difference between various corporations? Why such differences occur?
(2) What are the changes of the hydropower efficiency in time? Why?
(3) What are the influence factors for hydropower generation efficiency and what can one learn from those "best practices"?

The remainder of this paper is structured as follows: in Section 2, the authors review the literatures, considering the aspects and methods used for hydropower efficiency assessment; in Section 3, the theoretical framework and data resources supporting the model TOPSIS used are explained while the results and discussion are presented in Section 4. Finally, Section 5 outlines the concluding remarks and policy implications. This last part also highlights the contributions that the present study seeks to make as well as further development of this research.

2. Literature review

2.1. Economic and technological efficiencies

Efficiency analysis in relation to electricity generating was historically concentrated on distribution networks (Farsi and Filippini, 2004; Inglesi-Lotz and Blignaut, 2014). Studies analyzing the efficiency of electricity generating plants include Çelen (2013); Kleit and Terrell (2001); and Knittel (2002). Jamasb and Pollitt (2001) reviewed the frequency with which different input and output variables are used to model electricity distribution. The most widely-used inputs were number of employees, transformer capacity and network length while the most frequently-used outputs were units of energy delivered, number of customers and size of the service area. Kleit and Terrell (2001) used a Bayesian method to analyze the potential effects of deregulation on gains in electricity generation and found that deregulating electricity generation increases efficiency. A similar research by Knittel (2002) concluded that alternative regulatory programs provide firms with an incentive to increase efficiency. It can be seen that those variables generally represent good indicators which reflect the economic and technological efficiencies of electricity generation.

As for hydropower efficiency, Barros and Peypoch (2007) applied a random cost frontier method to demonstrate the role of competition and regulation in determining the technical efficiency of the hydroelectric generating plants in Portugal. Further analysis by Barros (2008) divided total productivity into technically efficient change and technological change and applied a DEA (Data Envelopment Analysis) model to analyze the hydropower efficiency of the Portugal Electricity Company. Using this model, Barros (2008) described the hydropower industry evolution, the inputs and outputs for efficiency assessment as well as best practices and benchmark management which were further applied to improve the efficiency of hydropower generation industry. Jha and Shrestha (2006) employed an input-oriented DEA model to evaluate the performance of hydropower plants of the Nepal Electricity Authority and presented the difference in the efficiency scores between the studied hydropower plants.

2.2. Environmental efficiency and social responsibility

Recent research outlined that environmental efficiency and social responsibility are important aspects of the hydropower efficiency. A literature review by Jamasb et al. (2004) revealed the absence of a universally accepted set of input and output variables for modeling electricity units. Liu and Liu (2012) studied the social responsibility, especially for the employee development of the electricity sector in China from the perspective of human resource management. Harmsen et al. (2014) analyzed the electricity efficiency policies and identified the possible implications for the Indian electricity sector. Noailly (2012) researched empirically the impact of alternative environmental policy instruments on technological innovations and found that two types of environmental policies have a positive impact on the direction and rate of technological innovation aiming to improve the energy efficiency of buildings.

Hydropower facilities provide many societal and environmental benefits in addition to producing the much needed renewable electricity. Numerous energy companies provided their corporate social responsibility reports, including Vattenfall (2011) and Brookfield Renewable Power (2013). As the Canadian Hydropower Association (Canadian Hydropower Association, 2013) suggested, Canadian hydropower industry should promote the technical, economic, social and environmental advantages of hydropower and advocate a responsible development and use of hydropower to meet present and future electricity needs in a sustainable manner. Established by the Canadian Electricity Association (2013b) for utilities across Canada, the Sustainable Electricity Company designation requires energy utilities to commit to standards on environmental management systems and guidance on social responsibility. This represents a significant milestone in making the electricity sector and companies more environmentally, socially, and economically responsible in their activities. Almost every Canadian hydropower company regularly presents their ongoing efforts in augmenting their corporate social responsibility. The changes observed in the energy market have obliged energy companies to react. However, strategic planning requires a sound and efficient basis if it is to yield successful results. Thus, efficiency analysis of hydropower generation at the level of the enterprise should consider the environmental benefits and social responsibility.

2.3. Methods for energy efficiency analysis

The literature review of a sample of recent publications on energy efficiency shows that they adopt one of the three main complementary efficiency methodologies: DEA (Wang et al., 2012, 2013; Yuan et al., 2013), which is of particular relevance to the present research, the Stochastic Frontier Model (Filippini and Hunt, 2012; Mugisha, 2007; Stern, 2012) and TOPSIS (Çelen, 2012; Çelen and Yalçın, 2012). These three methods represent branches of multi criteria decision making models. Since the DEA model does not impose any functional form on the data nor make any distributional assumptions for the inefficiency term, the previously mentioned TOPSIS method is frequently used in decision making (Afshar et al., 2011; Khazaeni et al., 2012).