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Diffusion of renewable energy technologies in South Korea on incorporating their competitive interrelationships

Sung-Yoon Huh [a,1], Chul-Yong Lee [b,*]

[a] Technology Management Economics and Policy Program, College of Engineering, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 151-742, South Korea
[b] Korea Energy Economics Institute (KEEI), 132 Naesonsunhwan-ro, Uiwang-si 437-713, Gyeonggi-do, South Korea

HIGHLIGHTS

- We develop a diffusion model incorporating the competition among renewables.
- A price function and a diffusion model are used in 2-step forecasting procedure.
- The annual demand through 2035 for five renewables in South Korea is forecasted.
- Wind power will maintain the largest market share in the electric power sector.
- The supply of geothermal energy will be larger than that of solar thermal energy.

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ABSTRACT

Renewable energy technologies (RETs) have attracted significant public attention for several reasons, the most important being that they are clean alternative energy sources that help reduce greenhouse gas emissions. To increase the probability that RETs will be successful, it is essential to reduce the uncertainty about its adoption with accurate long-term demand forecasting. This study develops a diffusion model that incorporates the effect of competitive interrelationships among renewable sources to forecast the growth pattern of five RETs: solar photovoltaic, wind power, and fuel cell in the electric power sector, and solar thermal and geothermal energy in the heating sector. The 2-step forecasting procedure is based on the Bayus, (1993. Manage. Sci. 39, 11, 1319–1333) price function and a diffusion model suggested by Hahn et al. (1994. Marketing Sci. 13, 3, 224–247). In an empirical analysis, the model is applied to the South Korean renewable energy market.

1. Introduction

There has been a great deal of experimentation and research regarding renewable energy technologies (RETs) since the first oil crisis in 1973 (Jacobsson and Johnson, 2000). Through the socio-economic changes such as the Kyoto Protocol of 1997, renewable energy sources (RESs) have received global attention because they have been regarded as a solution for oil depletion as well as for climate change. Renewable energy (RE) has also been given much emphasis owing to its potential of being a key industry that can lead national economic growth. RESs accounted for 16.7% of global final energy consumption in 2010. RE capacities showed high annual growth rates during 2006–2011; solar photovoltaic (SPV) power grew at 58%, wind power, 26%, and concentrating solar thermal power, 37% (REN21, 2012).

In general, RE uses lower technology levels and is less price competitive as compared to conventional fossil fuels. It is essential, therefore, to reduce the uncertainty regarding RE adoption, thereby enhancing its market value and success probability. Accurate forecasting of long-term demand for individual RESs takes precedence over other tasks in order to reduce this uncertainty. On establishing the future trend of individual RESs, the technology that would succeed in the market could be identified and, thus, become a strategic target. In addition, policies and strategies suitable to the RESs' life cycle can be designed on the basis of an accurate forecast.

Recently, several studies that forecast future growth patterns of RET have been published. Despite the fact that RE has distinctive features compared to conventional energy sources, in terms of innovation diffusion theory, most existing studies have not considered

* Corresponding author. Tel.: +82 31 420 2289; fax: +82 31 420 2162.
E-mail addresses: hsy1@snu.ac.kr (S.-Y. Huh), cylee@keei.re.kr (C.-Y. Lee).
[1] Tel.: +82 2 880 8386; fax: +82 2 873 7229.

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this issue; many types of RESs available lead to the existence of an innovation interrelationship among the various RESs, and finally, this interrelationship has an effect on the diffusion of individual RESs. As indicated by Mahajan and Peterson (1985), innovations do not exist in isolation, and one innovation in the social system may have an influence – either positive or negative – on the other. In the RE context, energy suppliers consider various factors – such as unit energy price, stability of supply, and geographical constraints – to choose the specific RES that gives them the highest utility. In this selection process, several RE alternatives are compared to one another, and hence, interaction occurs among them. That is, because some RESs such as SPV, wind power, and fuel cell diffuse through mutual competition, a diffusion model considering such competition should be used rather than estimating individual diffusion independently.

This study develops a diffusion model reflecting competition among RESs to forecast the growth pattern of an individual source more accurately. It is assumed that SPV, wind power, and fuel cell technologies compete against one another in electric power sector and that solar thermal and geothermal energy compete against each other in heating sector. The levelized cost of energy (LCOE) is considered to be a key variable that has a major effect on the competition process. The suggested model is composed of two steps. In step 1, the Bayus (1993) price function of individual RESs is estimated, followed by forecasting the LCOE of each source. In step 2, the diffusion model suggested by Hahn et al. (1994) – generally abbreviated as the HPKZ (Hahn, Park, Krishnamurthi, and Zoltners) model – is modified to reflect the competition among RESs. In step 2, the LCOE forecasted in step 1 is inserted into the model as a variable.

The proposed model is applied to the South Korean RE market for an empirical analysis. The current Korean RE market is in its initial stage, making accurate forecasting very meaningful. Besides, the Korean market's RE data are more accessible than that of other countries, thus making it suitable to use and, hence, verify the model.

The remainder of this paper is organized as follows. The next section provides a brief summary of existing RE literature, in which diffusion models were the main tools for analysis: their strengths, weaknesses, and limitations are indicated and the differentiation from our model is suggested. Section 3 introduces the two main estimation models used – the Bayus price function and HPKZ model – and explain the detailed procedure for integrating as well as applying them to RE diffusion forecasting. Section 4 discusses data collection, presents the empirical results, and suggests future diffusion trends along with related interpretations. The last section presents concluding remarks with policy implications, and provides the limitations of our approach as well as directions for future research.

2. Literature review: Applications of diffusion models to renewable energy analysis

In this study, an innovation diffusion model is used to forecast demand for RESs. Innovation diffusion models have been widely used in the field of social sciences to analyze the growth pattern of new technologies/products and to estimate their market potential. They have shown good representations of real market dynamics and their usefulness was proven in several business and academic fields.[2]

Among the many diffusion models, the seminal Bass (1969) model has been used in diverse field of studies. Although the Bass model shows good data fitness and forecasting accuracy, it has some limitations owing to several underlying assumptions which are established for model parsimony. To overcome its limitations, several extensions have been developed. Typical examples of such extensions are the models considering price as an influence on internal factors (Jain and Rao, 1990; Horsky, 1990; Bass et al., 1994), incorporating competition among technologies into the model (Peterson and Mahajan, 1978; Eliashberg and Jeuland, 1986; Hahn et al., 1994), reflecting the effect of contemporary economic circumstances (Frank, 2004), considering repurchase and multiple purchases (Olson and Choi, 1985; Bayus et al., 1989; Hahn et al., 1994; Danaher et al., 2001), and examining the effect of supply constraints on diffusion patterns (Jain et al., 1991; Ho et al., 2002).

Applications of such diffusion models to RETs are limited, both quantitatively and qualitatively. However, as RESs gained increasing public attention, many studies applied diffusion models to forecast their future growth patterns. Rao and Kishore (2010) reviewed different diffusion models and their applicability to RET diffusion analysis. They classified existing literature into four categories: (i) economies of scale, experience and learning curve approaches to establish cost reductions, (ii) economic analysis of RETs for their viability as compared to the given alternatives, (iii) stakeholders' perspectives, barrier analysis frameworks, and barrier mitigation approaches, and (iv) policy analysis and influences on RET adoption. They concluded that existing diffusion models could be useful tools to analyze diffusion mechanisms as well as to assess the effectiveness of different RET diffusion strategies.

In addition to Rao and Kishore's (2010) classification, research studies related with RET diffusions can be classified into four categories: (i) application of typical epidemic diffusion models to RETs, (ii) identifying factors promoting or impeding RET diffusion by qualitative analysis, including case studies (Jacobsson and Johnson, 2000; Tsoutsos and Stamboulis, 2005; Dinica, 2006; Jacobsson and Lauber, 2006), (iii) forecasting future trends of individual RES by a simulation technique such as an agent-based model (Sopha et al., 2011), and (iv) diffusion studies using other econometric methodologies (Isoard and Soria, 2001; Ibenholt, 2002; Söderholm and Klaassen, 2007; Kumbaroğlu et al., 2008). In this section, we introduce studies belonging to the first of the aforementioned categories, owing to the modeling similarity to our model, and describe our novel contributions as compared to them.

Purohit and Kandpal (2005) analyzed diffusion trends of four RETs (SPV, windmill, biogas, and producer gas-driven dual fuel engine) for irrigation water pumping and presented their future dissemination levels using the Bass, Gompertz, Logistic, and Pearl models. They showed that RET potential is achieved fastest in the case of the Logistic model, whereas the diffusion following the Gompertz model is the slowest; the remaining two models represent an intermediate diffusion trend as compared to the first two. The authors concluded that, in India, the dissemination of RETs for irrigation water pumping would not reach its maximum potential in another 25 years.

Rao and Kishore (2009) investigated growth patterns of wind power technology in several Indian states using the Bass model. The state-level data of cumulative wind power installed capacity is used to rank the diffusion in four states. On the basis of the difference in each state's wind power promotion policies, the composite policy index (CPI) of each state is calculated to prove the existence of a general correlation between CPI and the diffusion parameters. It was found that the diffusion model provides a good basis not only for the study of consumer markets but also for the study of capital intensive equipment such as wind power generators.

[2] Readers interested in an extensive review on the history, mathematical formulation, and applications of innovation diffusion models are advised to refer to existing review papers such as Mahajan et al. (1995), Geroski (2000), and Meade and Islam (2006).