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A multiple perspective modeling and simulation approach for renewable energy policy evaluation

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ABSTRACT

Environmental issues and dependence on fossil fuel sources including coal, oil, and natural gas, are the two most prevalent energy issues that are currently faced by the United States. Incorporation of renewable energy sources, a non-economical option in electricity generation compared to conventional sources that burn fossil fuels, promises a viable solution for both of these issues single-handedly. Several energy policies have concordantly been suggested to reduce the financial burden of adopting renewable energy technologies and make such technologies competitive with conventional sources throughout the US. In this work, we present a novel simulation framework to help policymakers assess and evaluate policies from different perspectives of its stakeholders. The proposed framework is composed of four modules: (1) a database which collates the economic, operational, and environmental data; (2) elucidation of policy which devises the policy for the simulation model; (3) a preliminary analysis which makes predictions for consumption, supply, and prices; and (4) a simulation model. After the validity of the proposed framework is demonstrated, a series of planned Florida renewable energy policies are implemented into our framework as a case study. The results obtained from the simulation and conclusions drawn on the assessment of current energy policies are presented with respect to the conflicting objectives of different stakeholders.

1. Introduction

Electricity consumption is growing at a rapid speed pacing with the increase in industrialization and urbanization around the globe. This rising demand of electricity brings out two major issues: (1) potential depletion of fossil fuel energy sources and (2) increasing greenhouse gases emissions which have an undeniable impact on pollution and global warming. In fact, in the US electricity generation is responsible for the greatest percentage of coal and natural gas consumption accounting for 92% and 31% respectively (US EIA, 2014c, 2015), and greenhouse gas (GHG) emission, accounting for 31% as of 2013 (US EIA, 2014d).

As a response to these alarming effects of electricity generation on GHG emissions and natural gas and coal consumption, there has been a significant rise in the global awareness of renewable energy. As of 2012, the US total investment in new renewable energy capacity was 34.2 billion; and the total renewable power capacity was 164 GW (REN21, 2013). Yet, these investments were not solely adequate to address the adoption barriers of renewable energy technology in the electricity market, which include the higher cost of renewable energy generation when compared to the cost of conventional energy technology; lack of effective government policies and regulations; poor public concern for aesthetics of renewable energy systems; poor utility rate structures; and lack of cost-effective access to transmission (US EPA, 2014).

With such a wide range of technical and economic barriers, there is no simple solution to adopt renewable energy technologies into the electricity market. To this end, several types of policy instruments are needed to regulate and control the electricity infrastructure and the established electricity market (Almutairi & Elhedhli, 2014; Gouchoe, Everette, & Haynes, 2002; He, Wang, & Wang, 2012; US EPA, 2014; Weidlich & Veit, 2008). All these various types of renewable energy policies can be grouped under two general categories: (1) financial incentives and (2) rules and regulations. Financial incentives are devised to help decrease the financial burden of renewable energy technologies in order to make this technology competitive against other conventional energy generation methods, and include tax credits, loans, rebates, and grant programs. Besides, rules and regulations are designed to overcome

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technical and economic barriers in electricity infrastructure and electricity market in order to increase the role of renewable energy sources in the electricity sector. Within this context, rules and regulations include net metering, renewable energy portfolio, etc. that regulate the electricity system (DSIRE, 2015a).

It is commonly agreed that, in order to successfully adopt the renewable energy sources into electricity sector, they need to be promoted with sufficient energy policies to main stakeholders in the sector. To this end, in this study, we develop a novel comprehensive simulation framework for the assessment and evaluation of different policies from the various perspectives of its stakeholders. The proposed simulation framework provides policymakers with an expedient tool to evaluate and quantify the benefits and detriments of potential policies in selection of an (near-) optimum policy considering its various stakeholders including customers, utilities, environmental agencies, and public service commissions. It also demonstrates how related stakeholders act or react to implementing such policies. As an empirical case study, the State of Florida is analyzed in detail to demonstrate the capabilities of the framework proposed in this research.

The remainder of the paper is organized as follows. In Section 1.1, the previous studies conducted on the energy policy evaluation are reviewed and our contribution in this work in relation to the presented literature is briefly discussed. In Section 1.2, the current energy profile of our considered case study of the State of Florida is described. In Sections 2 and 3, the details of our proposed framework and the results obtained on the considered case study are presented in detail, respectively. Finally, in Section 4, conclusions are drawn and future research venues are discussed for the presented study.

1.1. Literature review

Increasing global electricity demand, limited supply of non-renewable energy sources, increasing cost of electricity from fossil fuels and global warming have prompted the usage of renewable energy sources. However technical and economic barriers are still in effect of penetration of renewable energy in greater extents (Weidlich & Veit, 2008). Well-designed renewable energy policies play a crucial role in surpassing these barriers and dissolving the problems in the adoption of renewable energy sources to generate electric energy. Such energy policies can only be achieved via a thorough and comprehensive evaluation process that takes into account the characteristics of the entire energy system.

The studies in the literature approach the renewable energy integration problem from different viewpoints. Some studies shed light on the impacts and consequences of *existing energy policies* on the electricity market with an aim of understanding the response of the market to those investigated policies. These studies commonly consider each one of those existing policies as a separate case study and compare and contrast their advantages and disadvantage using varying qualitative and quantitative tools (Almutairi & Elhedhli, 2014; Chen, 2011; Gan, Eskeland, & Kolshus, 2007; Gouchoe et al., 2002; He et al., 2012; Yao & Chang, 2014). For instance, Gan et al. (2007) and Gouchoe et al. (2002) discuss the financial incentives and (Almutairi & Elhedhli, 2014; He et al., 2012) analyze carbon-cap, carbon trade and carbon tax policies in conjunction with the effects of these policies on carbon emission. While (Almutairi & Elhedhli, 2014; Gan et al., 2007; Gouchoe et al., 2002; He et al., 2012) focus on specific policies, Chen (2011) and Yao and Chang (2014) make long-term analysis of nation-wide energy policies in terms of their effect on GHG emissions mitigation and energy security, respectively. However, since all of these works focus on posterior information about the electricity market, they are quite limited in modeling and inferencing on changes in the renewable energy technology, electricity market, and preferences of stakeholders.

Other studies aim to give policy-makers a better understanding of the effects of *future policies* that would be implemented. The momentous goal of these studies is to assist policy-makers in policy design, considering current electricity system characteristics. The models presented within these studies can be grouped into three categories: analytic, economic, and fuzzy models. Analytic models in energy policy evaluation aim to measure and assess energy policies using multi-criteria decision making methods (MCDA) (Browne, O'Regan, & Moles, 2010; Kabak & Dagdeviren, 2012; Trappey, Wang, Ou, Trappey, & Li, 2014). Using these models, the effectiveness of a wide range of energy policies is investigated in terms of various criteria ranging from GHG emissions to security of electricity supply. While (Browne et al., 2010) compares the performance of an energy policy against that of an optimal policy (best one), Kabak and Dagdeviren (2012) and Trappey et al. (2014) give a single score to each considered policy by weighting different objectives. Even though MCDA-based studies provide quantitative analysis for each policy considering different objectives, they are quite limited in their abilities to model the system and heavily depend on expert opinion.

Economic models are also used to evaluate the effect of financial incentives on the economic burden of renewable energy technologies. Here, Zhang, Zhou, and Zhou (2014), Scatasta and Mennel (2009), Lee and Shih (2011), Reuter, Szolgayová, Fuss, and Obersteiner (2012), and Zhang et al. (2012) study the real option technique to handle uncertainties in electricity and carbon prices. In these studies, researchers generally view the system from either the investor or government perspective and give the results of different incentive rates. These models present precise information about the economic point of investments on renewable energy technologies. However, they lack the ability to concurrently consider other aspects of renewable energy policies, and the electricity supply and demand dynamics. The last group includes fuzzy models. These models can be considered to be valuable tools for evaluating energy policies due to their capability of modeling the socio-political side of energy policies. To date, however, only a few studies have used fuzzy models in this area. Here, Mutingi and Mbohwa (2014) provides a framework for the evaluation of renewable energy policies in South Africa using a fuzzy system dynamics paradigm to help understand the interaction among energy demand and supply. The key limitation of this study is that the presented results heavily depend on transformation functions and fuzzy rules, both of which need to be optimized. Table 1 presents a brief comparison of the aforementioned analytic, economic, and fuzzy models presented in the literature.

In addition to these studies, several simulation models have been proposed to evaluate different energy policy alternatives. Simulation is one of the most viable tools for analyzing the behavior of the electricity market and modeling complex electricity system. It provides a more accurate understanding of the complex interactions between different market participants and various market components. Accordingly, many simulation-based tools have been developed to model renewable energy integration into the electricity market (Bryant & Lempert, 2010; Connolly, Lund, Mathiesen, & Leahy, 2010; Mitchell, Nagrial, & Rizk, 2005; Sáenz & Celik, 2014; Sáenz, Celik, Asfour, & Son, 2012; Thanos, Bastani, Celik, & Chen, 2015). While these tools could be further modified for renewable energy policy evaluation (application-wise), their capabilities would still be limited by what is presented in the original design of the tool. Correspondingly, simulation models designed specifically for energy policy evaluation have been developed in the literature (Alishahi, Moghaddam, & Sheikh-El-Eslami, 2012; Damgacioglu, Alyamani, & Celik, 2015; Hsu, 2012; Movilla, Miguel, & Blázquez, 2013; Zhao, Mazhari, Celik, & Son, 2011). These