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Renewable energy policy performance in reducing CO_2 emissions

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ABSTRACT

The growth of fossil fuel power production and the consequent increase in the level of carbon dioxide (CO_2) emissions have set off an alarm signal worldwide. Different policies have been implemented to incentivize the development of renewable energy sources with the goal of reducing CO_2 emissions. Notwithstanding the different policies contribute to reduce greenhouse gas emissions through the incentives provided for renewable energy, a relevant question is which of these is the most efficient. However, within the context of oligopolistic competition, the answer is very sensitive to the operation of the system. In particular, significant changes in the results can be observed when considering or ignoring reserve constraints.

1. Introduction

The increment in the level of carbon dioxide (CO_2) emissi'ons has caused great concern worldwide. In 2009, power and heat generation from conventional sources was responsible for more than 40% of the CO_2 emissions worldwide (IEA, 2011). According to US-EIA (2013a) estimates, world energy consumption and CO_2 emissions are expected to grow 56% and 46%, respectively, between 2010 and 2040.

Many countries are committed to reducing greenhouse gas emissions. According to US-EIA (2013a), European OECD countries are committed to reducing greenhouse gas emissions to 20% (base year 1990) by 2020 and between 80% and 95% (base year 1990) by 2050. To meet these goals, the integration of renewable energy (RE) in the energy matrix has been identified as essential (IPCC, 2011; Jäger-Waldau et al., 2011).

Commonly used RE policies are: carbon taxes, feed-in tariffs, premium payments, quota systems, auctions and cap and trade systems, as it is pointed out by Pérez de Arce and Sauma (2016). There is evidence that these policies have paved the way for renewable energy and, therefore, have contributed to the reduction of greenhouse gases (Agnolucci, 2006; García and Román, 2014; Hinrichs-Rahlwes, 2013; Olimpio et al., 2011; Ortega et al., 2013; Pal Verma and Kumar, 2013; Powers, 2012; Wüstenhagen and Bilharz, 2006).

Although different policies have contributed to reduce greenhouse gases through incentives provided to RE, there is also a concern about what is the best policy to face the new challenges in the development of RE (Johnston et al., 2008; Lesser and Su, 2008; Su et al., 2008; Albadi and El-Saadany, 2009; Farrell, 2009; Couture et al., 2010; Couture and Gagnon, 2010; Guzowski and Recalde, 2010; Batlle, 2011; Cansino et al., 2011; Klessmann et al., 2011; Oikonomou et al., 2011; Kitzing et al., 2012; Schallenberg-Rodriguez and Haas, 2012; Tükenmez and Demireli, 2012; Fouquet, 2013; Al-Amir and Abu-Hijleh, 2013; Cherrington et al., 2013; Jenner et al., 2013; Uran and Krajcar, 2013; Stokes, 2013; Pérez de Arce and Sauma, 2016; Schallenberg-Rodriguez, 2014). The question of which policy is the most efficient has more than one answer if we pay attention to the results of the different studies existing in the literature. Berry and Jaccard (2001) identify that the implementation of a quota system has the advantage of ensuring a more diverse mix of RE. Espey (2001)

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recognizes that the quota system has the advantage of generating a high degree of competition between generators or developers of RE, greater freedom in selecting the type of RE and less financial burden on governments. Menanteau et al. (2003) suggest that a feed-in tariff policy is more efficient in practice than a bidding system, but recognize that, theoretically, a quota system with green certificates may be more efficient. Palmer and Burtraw (2005) find that a quota obligation can be a good policy to promote RE and reduce emissions, and it is more cost-effective than tax credits. Rowlands (2005) recommends a feed-in tariff policy because it would allow the supply of RE to diversify, compared to a quota system. Mitchell et al. (2006) indicate that feed-in tariffs are more effective than quota systems. Lewis and Wiser (2007) analyze different incentive policies and identify the feed-in tariff as a successful policy from a qualitative perspective. Green et al. (2007) highlight that carbon tax policy could help to reduce emissions associated with conventional energy. Lipp (2007) argues that feed-in tariff policy is more cost-effective than a quota system. Wiser et al. (2007) emphasize the experience and success of the quota system in the United States and give some recommendations to be applied at the federal level. Butler and Neuhoff (2008) show that, in practice, the feed-in tariff applied in Germany has allowed lower prices for wind energy and greater competition compared with the UK's quota and auction mechanisms. Fouquet and Johansson (2008) recommend implementing a feed-in tariff instead of a quota system with tradable green certificates, as it allows for greater competition in the market. Laird and Stefes (2009) argue that the success of the feed-in tariff policy applied in Germany could be explained due to institutional and social factors. Falconett and Nagasaka (2010) conclude that feed-in tariffs are the best mechanisms to promote PV systems and wind energy projects while green certificate mechanisms stimulate the most competitive technologies, such as hydropower. In addition, it is shown that government grants and carbon credits are secondary support mechanisms compared to feed-in tariffs and RE certificates. Fischer (2010) recognizes that a quota system with green certificate combines the benefits of both a subsidy and an implicit tax; however the price impacts can be ambiguous. Woodman and Mitchell (2011) indicate that a quota system has limitations that make it less efficient than a feed-in tariff. Limpaitoon et al. (2011) illustrate that a carbon tax policy would not necessarily reduce emissions in the presence of a strategic behavior of the market players. Wood and Dow (2011) identify weaknesses in the quota system applied in the UK, arguing the need for moving to a feed-in tariff. Woodman and Mitchell (2011) mention that one of the main differences between a quota system and a feed-in tariff is that the latter has the advantage of managing market risk. Dong (2012) argues that policies such as feed-in tariffs are more efficient than quota systems. Verbruggen and Lauber (2012) conclude that a feed-in tariff policy has a better performance than a system of tradable green certificates. In Hart and Marcellino (2012), the authors highlight the significant role played by the feed-in tariff in Germany and the quota system, also known as Renewable Portfolio Standards (RPS) in the United States, recommending the continuation of such policies. Martin and Rice (2012) identify that the implementation of a carbon tax policy was important for the development of RE in Australia. Kitzing (2014) identifies, using mean-variance portfolio theory, that a feed-in tariff requires lower subsidies than a premium payment policy. Oak et al. (2014), in a study based on data from onshore wind in the UK, determine that the premium payment and quota systems present better performances than feed-in tariffs.

When identifying which is the most efficient policy in reducing CO_2 emissions, the market structure becomes very relevant, as shown in Pérez de Arce and Sauma (2016). In this study, we consider a power market where generation firms compete à la Cournot. This framework is common in power markets (Yang et al., 2002; Neuhoff et al., 2005; Sauma and Oren, 2006; Gutiérrez-Alcaraz and Sheblé, 2006; Hu and Ralph, 2007; Wang et al., 2007; Sauma, 2009; Downward, 2010; Yang et al., 2011; Ladjici and Boudour, 2011; Moghddas-Tafreshi et al., 2011).[1] The model used here is based on the oligopolistic model built in Pérez de Arce and Sauma (2016), incorporating new features like uncertainty and variability of renewable resources and demand, marginal generation costs, and reserve constraints.

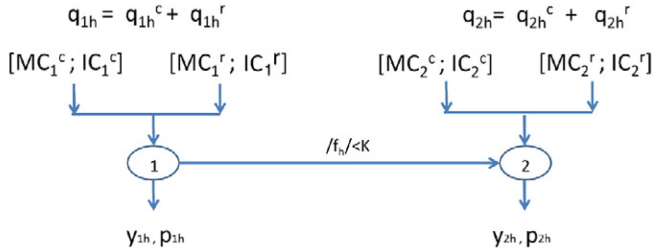

Fig. 1. Two-node power network.

2. The model

2.1. Model hypotheses and assumptions

Our model is built based on the model in Pérez de Arce and Sauma (2016). The model considers two nodes (indexed by i) linked by a transmission line, as shown in Fig. 1. In each node i there is a generation firm, which can invest in a conventional source power plant and/or in a renewable source power plant. Different from Pérez de Arce and Sauma's model, our model incorporates uncertainty and the variability of both renewable resources and demand, among other differences from our previous work. In particular, our model considers n scenarios representing demand and renewable resources availability represented by subscript h, since they correspond to representative hours throughout the year. Each scenario occurs with probability φ_h, which corresponds to the number of hours with a similar demand and wind and solar availability throughout the year divided by 8760. The probability of each scenario occurring at a particular hour of the year is $1/n$.

The main decision variables of the model are the total amount of energy injected into node i in scenario h, q_{ih}, (which corresponds to the sum of the conventional, q_{ih}^c, and renewable, q_{ih}^r, power generation in node i in scenario h), the demand satisfied in node i in scenario h, y_{ih}, the power flow through the transmission line in scenario h, f_h, the nodal price (i.e., the Langrange multiplier of the energy balance constraint) in node i in scenario h, p_{ih}, the Langrange multiplier of the transmission capacity constraints in node i in scenario h, η_{ih}, the conventional generation capacity installed in node i, K_i^c, and the renewable generation capacity installed in node i, K_i^r. We assume a linear inverse demand function in each node and in each scenario given by $p_{ih} = a_i \cdot E_h^{Demand} - b_i \cdot y_{ih}$, where E_h^{Demand} is a factor accounting for the variability of the peak demand in scenario h and a_i and b_i are positive constants of the price-responsive demand curve in node i.

Regarding the main parameters used in the model, K is the capacity of the transmission line, $\overline{K}_i^c$ is the maximum conventional generation capacity that can be installed in node i, $\overline{K}_i^r$ is the maximum renewable generation capacity that can be installed in node i, IC_i^c is the hourly equivalent per MW conventional generation investment

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[1] It is worth to remark that the Cournot assumption may be unsuitable, as well as the Bertrand assumption, when generators are allowed to submit multiple flat bids for sections of their capacity, as it occurs in some real-world pools (Klemperer and Meyer, 1989). Moreover, wholesale electricity markets are large and complex for the use of analytical methods because they feature imperfect competition, very low demand elasticity, discontinuously convex supply functions, high frequency repeated trading, heterogeneous agents and high potential for collusion (Wilson, 2002).