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Renewable energies impacting the optimal generation mix: The case of the Iberian Electricity Market

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ABSTRACT

In the last few decades, electricity markets have undergone extensive reforms. A process of liberalizing electricity markets has been implemented by several countries, reducing the incumbents' market power. Thus, generation and retail are open to competition, while transmission and distribution remain regulated. Furthermore, the need to comply with the targets set by the Kyoto Protocol has boosted the installed capacity of renewable energy sources, such as wind power. Therefore, it is important to study what the impact of a renewable source like wind power will be on the optimal generation capacity mix, assuming producers can invest in other technologies and the wholesale market is open to competition. In this article, we assume two alternative generation technologies – wind and combined cycle gas turbines – as a simplifying assumption. We develop a two-stage model for the Iberian Electricity Market, where the choice of the capacity construction occurs in the first-stage, before electricity demand is known, and the optimal outputs and daily equilibrium prices are obtained in the second-stage, under the assumption that electricity demand does not exceed installed capacity. The application of this model reveals that producers can be expected to increase their renewable generation capacity (wind power).

1. Introduction

Since its discovery, electricity has become an indispensable good for each home and an essential input for industry in probably every economy. Until the 80's vertically integrated as well as public and private monopolies were the dominant market model. For instance, in the USA large production and transmission state-owned companies, municipal firms, distribution cooperatives or regulated private monopolies could be observed.

However, this scenario has changed drastically in the past two decades. The formation of a more competitive electricity market is currently taking place in many countries. In the EU (European Union), for example, the first great step to a reorganization process of the electricity market began in 1996, with the Directive 96/92/EC, and since then several additional measures have been taken in order to achieve an Internal Electricity Market. To accomplish this goal, member states have increased their capacity of cross-border transmission lines through the creation of regional markets. As a result of this trend, Portugal and Spain decided to create an Iberian Electricity Market (MIBEL (*Mercado Ibérico de Electricidade*)).

Following the steps of the UK and the Scandinavian countries in the reorganization process of their electricity markets, Iberian wholesale generation and retail were opened to competition, and the (incentive) regulation of transmission and distribution networks was established. The Iberian wholesale spot market was created, in which the rules of a liberalized market prevailed. This is the market on which the present article focuses.

Having this in mind, we can argue that the MIBEL is based on principles of a single price for the whole peninsula, free competition, transparency, equal access among stakeholders, and economic efficiency to the consumer's benefit in both countries [1,2].

Several technologies can be employed to produce electricity. Nevertheless, the growing concerns of global warming and the scarcity of fossil resources have led to an increase of State measures to promote renewable energy sources. For example, the European Union (EU) has set the goal of satisfying 20% of electrical demand with renewable energy by 2020 [3]; and for Portugal and Spain, the targets are 31% and 20%, respectively [4]. According to Lund et al. [5] there are three phases of implementing renewable energy sources: (i) the introduction phase where the renewable share has little or no participation in the energy system; (ii) the large-scale introduction phase where the renewable energy share in the energy system is greater, making the energy system more complex and requiring the stabilization of the grid; and (iii) the 100 percent renewable energy

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phase characterized by an energy system which only is comprised of renewable energy and where new renewable investments need to be compared with renewable energy sources, instead of nuclear or fossil fuel sources. Although the last phase is the ideal, the integration of renewable energy in the EU electricity grid is in the first phase [5].

Nevertheless, wind power has played a key role in changing the paradigm. According to the GWEC (Global Wind Energy Council) [6], *"the global wind power market grew by about 6% compared to 2010, and the 40.5 GW of new wind power brought on line in 2011 represents investments of more than €50 billion (about $68 billion)"*. In Europe, new installed capacity of wind power reached 10,281 MW in 2011. Currently, the entire installed capacity of wind power in Europe is 96.6 GW. Even in Portugal and Spain, wind power has had a significant growth. During 2006–2011 the installed capacity of wind power increased 169% in Portugal (from 1517 MW to 4081 MW) and 74% in Spain (from 11,521 MW to 20,733 MW). This growth allowed an important contribution of wind to power generation, reaching 18.6% for Portugal and 16.3% for Spain, in 2011 [7,8]. Consequently, it can be claimed that the technology used to produce wind power is mature, competitive, and well spread in the global market.

Given the electricity market has been subject to extensive reforms and wind power has experienced impressive growth, the following research question arises: what is the effect of well-developed renewable energy sources, like wind power, on the generation capacity mix of a competitive market, such as in the Iberian wholesale electricity market?

Currently, this is a crucial question since both Portugal and Spain have already approved the reduction of subsidies to wind power producers. In light of these measures, the purpose of this study is to provide the necessary tools for understanding the relationship between renewable energy sources and the optimal generation capacity mix in a liberalized, competitive market. Furthermore, since the literature on this specific topic is scarce, this article also aims to fill this gap.

Despite its current appeal as a clean energy, wind power is an intermittent energy source which needs to be coordinated with other energy sources such as heat supply [5]. Bearing this in mind, the CCGT (combined cycle gas turbine power) was chosen to represent the optimal generation capacity mix because its contribution for the Iberian Electricity Market has become increasingly important. Indeed, in 2011, Portugal had an installed capacity of CCGT which accounted for 20.3% of the total installed capacity, and CCGT produced 21.3% of the total power generation, being the main technology responsible for producing electricity in thermal generation [7]. In Spain, values are slightly different. In 2011, the Spanish installed capacity of CCGT reached 25% and CCGT power contributed to approximately 20% of total power generation [8]. As is the case in Portugal, CCGT was the primarily technology for the production of electricity in thermal generation. Furthermore, the MIBEL increased the installed capacity of CCGT power by 65%, during 2006–2011 [7,8].

The methodology used was the following: after reviewing the literature focused on the impact of wind power on the generation capacity mix, we follow the article developed by Milstein and Tishler [9]. This paper was applied to the Israeli market, which has been subject to extensive reforms in order to deregulate the electricity market, since it was dominated by state-owned vertically integrated electric utility. Given underinvestment is one of the major concerns to policymakers in deregulated electricity markets, this article offers a formal model of endogenous capacity with uncertain demand to aid the regulatory body in understanding that underinvestment is due to the rational behavior of profit-seeking producers. Later, the same authors applied the base model to the same market in order to aid the regulatory body in realizing the relationship between renewable energy, the optimal generation mix, and electricity price level and volatility [10]. Therefore, to explore the connection between renewable energy sources and the optimal generation capacity mix in a competitive wholesale electricity market, this article applies and solves this theoretical model to the Iberian Electricity Market. To that end, we present a two-stage game of endogenous investments and operations in a competitive electricity market with wind and CCGT technologies under the uncertainties of supply and demand. In the first-stage of the game, each producer decides on its capacity investment in order to maximize expected profits. In the second-stage of the game, the producer selects its daily electricity production subject to capacity availability, and equilibrium prices are determined. The game is developed under the Cournot framework and solved using *MATLAB* software.

The article proceeds as follows: Chapter 2 makes a literature survey about the research question; Chapter 3 presents the model; Chapter 4 applies the model to the Iberian Electricity Market and presents the main results; the last chapter concludes with discussion and implications for future research.

2. A literature review

The literature on the impact of renewable energy sources on the generation capacity mix is scarce. Indeed, the literature on wind power says little about how this power source may affect the generation capacity mix. Thus, as the main objectives of this article are to resolve this shortcoming and answer the question of whether renewable energy sources will have an impact on the generation capacity mix in the MIBEL; the literature survey will only focus on the main articles that address this specific issue.

Some recent studies have started to approach this topic, as there are serious concerns either as to the way in which electricity power planning will change and as to how the management of existing electricity systems will develop.

The research question has been approached in two ways: some studies use the idea of the credit concept and others use the screening curve methodology. However, there is a set of studies that use other methods to address the same question. The different ways to address the problem will be explained below.

2.1. The capacity credit concept

Wind power is an intermittent energy, where its output can vary drastically from day to day and even over the 24 h of a single day. Thus, to ensure the security of supply, total substitution of conventional power plants by wind turbines is improbable [11]. Nevertheless, it is possible to achieve a safe reduction in the installed capacity of conventional power with a sufficient increase in the installed capacity of wind power. This gain in capacity reduction is usually called *capacity credit*.

Some of the main authors to look into this matter were Strbac et al. [12]. The authors developed a study exploring the costs and benefits of integrating wind power into the UK electricity market. The analysis concludes that wind generation only replaces a relatively small amount of conventional capacity. Thus, it is necessary to preserve a significant proportion of conventional capacity to ensure the security of supply.

Another important study was developed by Oswald et al. [13]. The study developed a model that analyzed the dynamic behavior, the volatility and the implications of 25 GW of wind power within the UK power system. The authors concluded that, given that wind power is a volatile power source, the electrical system would need to maintain the fossil fuel plants to handle peak demand. Therefore, the ability of wind power capacity to replace fossil power capacity may be compromised, namely in peak demand situations.

Additionally, Weigt [11] sought to analyze the reserve capacity and the impact of wind power on generation costs and market price in Germany. Regarding capacity replacement potential, and in