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Renewable energy scenarios in the Portuguese electricity system

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ABSTRACT

The growing concerns about climate change and security of supply opened way to a significant investment in the exploitation of RES (renewable energy sources) for electricity generation. The possibility of achieving 100% RES systems is being debated but concerns about costs, storage and backup capacity still prevail. This paper addresses the topic of renewable energy scenarios for the electricity sector, analyzing different possible future strategies for the Portuguese system. Each one of these strategies is characterized according to the expected electricity consumption and renewable share, with the final aim of analyzing a possible 100% RES scenario. The energy system analysis tool EnergyPLAN was used for simulating each scenario for a one year period. The 100% RES scenario is found to be theoretically possible but a significant increase on the total capacity of the system would be necessary to ensure no shortfall during the summer season. The outcome would be the existence of critical excess electricity production during the winter and also a significant increase of the total cost of the system. The importance of the interconnection as stabilization measure along with the inclusion of storage systems is discussed for a system highly dependent on renewable energy sources.

1. Introduction

The development of electricity systems strongly supported on RES (Renewable Energy Sources) can be attributed to environmental, economic and political factors. This is particularly evident in Europe, with the recent documents for the energy sector reinforcing this RES strategy. This support for RES investments aims to have a positive effect on the economic development, reducing also the negative environmental impacts often associated to the electricity production sector and contributing to reduce the European trade deficit in energy commodities [1]. Although recognizing the relevance of RES for a sustainable electricity system, it is important to acknowledge that RES projects can have important impacts on the grid management and even on the electricity bills for the consumers, as their high capital costs frequently require adequate incentives for such investments [2,3]. Also, wind, sun or even rain can be difficult to predict and to store creating additional complexity on matching electricity demand and supply. One of the main constraint faced by the production of electricity from RES comes from its intermittent or variable nature, which creates increasing need for reliable storage systems and represents a challenge for security of supply [4]. Notwithstanding, the importance of RES has been increasing and the possibility of reaching energy systems relying completely on these sources is now being explored in different countries and by different authors.

Cósic B. et al. [5] for example outlined a system for 100% renewable energy sector in Macedonia. Lund and Mathiesen [6] concluded that a 100% renewable energy supply based on domestic resources is physically possible for Denmark in 2030 but the design of these systems is a very complex process. Also in Denmark, the methodology proposed by Mathiesen et al. [7], in the context of the policies implemented to reduce GHG (greenhouse gas) emissions, presents a technical analysis for developing a self-sufficient system for the country's prosperity. Mason et al. [8] proposed and analyzed a renewable electricity generation system for New Zealand and more recently least cost 100% RES options for supplying the Australian Electricity Market were presented [9].

The topic of fully renewable energy systems is being debated also at a European level, in recent studies [10–14]. Trainer [10] concluded that 100% renewable supply for Europe would not be affordable and the storage and significant backup generation required by the intermittent renewable power production are major concerns for these RES systems [12–14]. Notwithstanding these drawbacks, the Global Energy Network Institute reports show a more optimistic scenario raising the possibility of having several countries electricity powered by 100% renewable energies in the

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near future (http://www.geni.org/globalenergy/research/index.shtml, consulted on February 2014).

Portugal remains as one of the European Union countries with the highest energy importation dependency rate. However, there is a perceptible growing importance of endogenous energy resources, especially regarding the production of electricity. Studies such as REN (Rede Elétrica Nacional) [15] and DGEG (Direção Geral de Energia e Geologia) [16] established that the internal production for the next years would strongly rely on the expansion of the hydro and wind installed capacity combined with a special emphasis on the development of solar energy and other RES such as biomass, biogas, geothermal and wave energy. Even the recently published National Plan for Renewable Energies [17] still assumes an increase of most RES much close to DGEG [16] but more moderate than REN [15]. Krajačić G. et al. [18], presented already the application of a computational model for the production of electricity in Portugal in a possible 100% RES system. The results "demonstrated that the solution preferred 100% renewable hydropower and wind energy", although the latter should be implemented in combination with "reversible hydroelectric and pumping capacity".

In general, the complexity of the systems under analysis is evident both from the data and from the model effort required. These systems require a simulation of possible future scenarios, through the adoption of planning models based on computing tools. The models used for the analysis are frequently supported on the computation of costs of electricity generation, CO_2 emissions and external costs and benefits. These studies have been accompanied by computer tools which assist within the decision-making process and can be used to analyze the integration of renewable energies [19].

This paper aims to investigate different renewable energy scenarios for electricity supply in Portugal. The research departs from the 2010 Reference Scenario and the outcomes of increasing RES levels are analyzed. For the analysis, this paper relies on the use of the EnergyPLAN one of the best-known models in the energy planning area [20,21]. The model was adapted then to the Portuguese case and the final aim is simulating a 100% renewable electricity system.

2. Renewable scenarios within the Portuguese electricity system

The Portuguese electricity system is mainly supported on thermal power plants, hydro and wind power. In what concerns thermal power, most of the electricity production comes from natural gas and coal and to a less extent from biomass. RES cogeneration and dedicated biomass represented about 6% of the total electricity produced in 2012. As for wind power, its contribution was about 23.5% of the total electricity produced and hydro contributed with 13% [22]. However, the values of RES based electricity production, and in particular of hydro, are highly uncertain depending on the climate conditions of each year. For example, in 2010, RES represented 54.6% of the total electricity produced in Portugal but in 2012, this value was only 43.2% [22,23]. The Portuguese system, is only interconnect with Spain allowing for limited capacity for importations and exportations, traded under the Iberian market.

For the analysis of different RES electricity systems for Portugal, free scenarios other than the Reference were established as follows:

1. Reference Scenario: model validation based on 2010 as a reference year;
2. Scenario 1: Scenario for 2020 based on values presented in the 2011 National Action-Plan for Renewable Energies [16];
3. Scenario 2: Scenario for 2022 based on values presented in the Development and Investment Plan for the National Electricity Grid 2012–2017 (2022) [15];
4. Scenario 3: 100% renewable scenario with total replacement of fossil fuels by renewable energies, assuming 2020 (Scenario 1) consumption projections. This scenario was elaborated by the authors.

EnergyPLAN model was used for the analysis for a one year time frame. The main inputs for the model were established by the projections of hourly consumption, RES and cogeneration installed power and hourly production, dam inflows, installed power of thermal power plants, hourly import and export balance and interconnection capacity. The outputs were represented by the hourly thermal power production, the fuel consumption, import/export balance and cost of the system. For each scenario, a technical analysis was undertaken. As for importations and exportations, their analysis go much beyond the pure technical perspective, depending on the strategic behavior of the electricity operators under the market conditions and prices. As the focus of this paper is mainly the analysis of the impacts of different RES scenarios under a pure technical optimization procedure, the economic dimension of the interconnection and the market prices and elasticity were not included in the optimization model. However, the marginal cost of each scenario is also computed and analyzed according to the technical outputs of the model.

2.1. Reference Scenario and model validation

The technical data included in Reference Scenario were supported on public data from the National Grid system Operator (REN). This scenario aims mainly to validate the model according to the actual operation of the system in 2010. The results were then compared with the technical data of REN, allowing to create a reference model which formed the basis for the construction of the following scenarios.

As mentioned before, economic analyses are not included in the optimization procedure. However, being the Portuguese system interconnect with Spain the possibility of importations and exportations must be included in the model. Also, a minimum production stabilization rate equal to 30% was assumed, to ensure the stability of the electricity grid with dispatching technologies.

For the validation of the model, the results obtained with EnergyPLAN 2010 scenario are compared to the REN data, as described in Table 1.

The results demonstrate the usefulness of the model for the technical simulation of the electricity system. As for importation and exportation balance a comparison would not be valid as the REN output is mainly explained by the strategic behavior of the electricity players in the Iberian market and would not be fully captured by the technical optimization procedure. Although

Table 1
Results of the model validation.

	Technical data 2010 (REN) (TWh/year)	Model output (EnergyPLAN) (TWh/year)	Difference (%)
Demand	52.3	52.3	−0.09
Wind	9.04	9.04	−0.04
Photovoltaic	0.21	0.2	2.1
Run-of-the-river	9.97	9.8	1.7
Dams	6.52	6.49	0.4
Thermopower plants	17.61	17.52	0.52
Cogeneration and biomass	7.33	7.33	0.0

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