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ANALYSIS OF SOURCES OF RISK AND UNCERTAINTIES IN THE ELECTRICITY SYSTEM

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ABSTRACT

Electricity power planning is a serious national task that encompasses not only forecasts but more importantly the evolution in short, medium and long term of each element that composes the assumptions, the constraints and/or the parameters of the planning model. Deterministic models can bring simplicity to the electricity power planning but do not consider the uncertainties and sources of risk of the electricity system. On the other hand, stochastic models tend to include the behavior of one or more uncertain parameters that are critical to obtain a robust solution, being however more detailed and lengthy than deterministic models. The aim of this work was to identify the major sources of risk and uncertainties facing electricity system, representing valuable input for the electricit planner task. From this study it can be observed that several different behaviours for each uncertain parameter can be found along a time horizon. Thus, it is concluded that reling on average lowers can represent a reductionist approach and in order to obtain more reliable scenarios for future electricity system, the statistical charcateristics of each parameter should be considered in the electricity power planning.

INTRODUCTION

Electricity is an indispensable good for society development and growth of a nation, stimulating the economic and technological development of a country (Prasad et al. 2014). Electricity has special characteristics that make it very different from other commodities traded in competitive markets, namely the need for instant and continuous generation and consumption, non-storability, high variability in demand over a day and season and non-traceability.
Electricity power systems are large-scale, complex engineering systems encompassing short- and long-term electricity power planning and management. Short-term electricity power planning also known as unit commitment (UC) problem aims to find the optimal start-up and shutdown schedules for all power generators composing a system, under operational constraints (Pereira et al. 2013). Long-term electricity power planning also known as generation expansion planning (GEP) problem aims to determine how many units of what type of power generators to build at which year and how much electricity should be produced by each type of generator (Pereira et al. 2011). In both short- and long-term power planning the objective is to reach a solution that minimizes the total system cost while meeting electricity demand at every time in the planning horizon.
Several aspects characterizing this new era of knowledge are driven electricity systems to adapt and evolve, forcing to consider relations within society and environment, technology development and political goals (Möst & Keles 2010). These transformations had increased uncertainties in short- and long-term, bringing with it more complexity to the planning process and increasing ambiguity and difficulty in the decision-making.
The uncertainties can be generally distinguished in two categories: technical and economic uncertainties (Soroudi & Amraee 2013). Technical uncertainties can be further divided into topological parameters and operational parameters. Topological parameters encompass failure or forced outage of lines, generators or metering devices, while operational parameters are related with operation decisions, namely demand and generation values in power systems. Economic

uncertainties cover microeconomics and macroeconomics. Microeconomic parameters include fuel supply, production costs, business taxes, labour and raw materials. Uncertainties related with regulation or deregulation, environmental policies, economic growth, unemployment rates, gross domestic product (GDP) and interest rates are included in macroeconomic parameters.

One efficient technique recognized and used worldwide for electricity power planning is scenario generation (Santos et al. 2014). Scenarios help to explore what, how and if future pathways are feasible to achieve predefined goals. Traditionally, a set of future scenarios is built on assumptions and constraints, based on deterministic values to all variables and parameters. Even with sensitivity analysis a posteriori, that allows determining which variable(s) influences most electricity power planning, uncertainties remains unquantified (Pye et al. 2015). Not properly considering uncertainties when modelling electricity power systems can turn seemingly cost-effective results into obsolete and inadequate options (Vithayasrichareon & MacGill 2012; Fortes et al. 2008).

This work aims to point out the main uncertainties facing future Portuguese electricity power system, considering the large penetration of renewable sources of variable output in the matrix and the high dependence of external supply of fossil fuel sources.

The paper is organized as follows. A literature review on power systems' uncertain parameters follows this introduction. Then, the methodology used in this study is presented and, subsequently, are the results and discussion. At last, the main conclusions of this work are shown.

LITERATURE REVIEW

Fortes et al. (2008) analysed the fragilities of the Portuguese power system associated with the development of deterministic long term energy scenarios. A stochastic approach was adopted, using fossil energy prices and energy demand as uncertain parameters, and the main conclusion of the work was that different drivers result in divergent energy scenarios.

Kim et al. (2012) focused their work on the uncertainties facing the electricity production costs by conventional and renewable technologies. They applied Monte Carlo simulation to handle uncertainties, such as learning rate of technologies, fuel prices and carbon prices. However they assumed that a normal distribution would fit all the uncertain parameters.

Pye et al. (2015) explored the uncertainties affecting policy goals to the transition of the UK energy systems to meet decarbonisation and security goals. The uncertainties tackled were investment costs of power generation technologies, building rates, biomass availability and resources prices (fossil fuel and biomass), for which the probability distribution functions (pdf) were assumed to be triangular distribution due to its validity, in view of lack of data.

Uncertainties in the energy sector driven by climate change and environmental constraints have gained attention in recent years as documented in many works (Schaeffer et al. 2012; Pilli-Sihvola et al. 2010; Lucena et al. 2010; Lucena et al. 2009). A review of the vulnerability of the energy sector to climate change was conducted by Schaeffer et al. (2012) comprising the contribution of relevant authors within their strategic studies, research workshops, development forums and international conferences on the Climate and Energy subject. This review demonstrated overall impacts on each renewable and fossil fuel sources affecting resource endowments, energy supply, transmission, distribution and transfers, energy use, infrastructure siting and finally, cross-sector impacts. Pilli-Sihvola et al. (2010) demonstrated a significant and clear relationship between electricity demand and temperature variation. They argue that climate warming will lead eventually to a decrease in future electricity costs for the Central and North Europe due to a decrease in heating needs, in opposition to an increase of the electricity costs in Southern Europe in consequence of the increase of cooling needs. In other study, encompassing the vulnerability of the Brazilian energy system to climate change, Lucena et al. (2009) demonstrated its impacts on the hydropower generation and liquid biofuels production, and later, in the wind power potential (Lucena et al. 2010).

Other studies have emphasised the uncertainties related to the large contribution of sources of variable output in the power systems, namely wind and solar power (Santos et al. 2015; Ludig et al. 2015; Pereira 2012; Pérez-Arriaga 2011). These uncertainties are focused on source availability (e.g. region of the power plant to be implanted, height, space and number of turbines), natural fluctuation (throughout the day, throughout the year) and climate change.

METHODOLOGY

A set of variables considered in electricity systems were selected to the study. The selection process was carried out bearing in mind the uncertainties that could affect mostly the long-term electricity power planning for the Portuguese case. For this purpose, a Wilson matrix was used, presented in Figure 1.

LEVEL OF IMPACT \ DEGREE OF UNCERTAINTY	Low	Medium	High
High	**Critical planning issues** Highly relevant and fairly predictable (can often be based on existing projections).	**Important scenario drivers** Extremely important and fairly certain. Should be based on projections but potential discontinuities also should be investigated.	**Critical scenario drivers** Factors and forces essential for success and highly unpredictable.
Medium	**Important planning issues** Relevant and very predictable.	**Important planning issues** Relevant and somewhat predictable.	**Important scenario drivers** Relevant issues that are highly uncertain.
Low	**Monitorable issues** Related to the decision focus but not critical.	**Monitorable issues** Related but not crucial to the decision focus.	**Issues to monitor and reassess impact** Highly unpredictable forces that do not have an immediate impact on the decision focus.

Figure 1: Wilson matrix to identify the risk degree of power planning parameters.

The variables selected for this study were i) renewable sources of variable output (hydro, wind and solar), due to their large integration in the actual electricity system; ii) future demand, since historical data does not reflect its behaviour in the last years; and iii) fossil fuel prices (coal and natural gas) due to the large dependency of external suppliers.

For each group of uncertain parameters, both qualitative and quantitative analysis was made. Qualitative analysis was based on literature while quantitative analysis was performed based on real data provided from national reports and energy-based institutions.

The data to perform the analysis of time variability of renewable sources were obtained from the electricity production within frames of 15 minutes, since 2007, provided from REN – National Network of Energy (In Portugal, they operate the main transport infrastructure and they undertake the overall management of the National Electric System and the National Natural Gas System). For each technology, the load factor or capacity factor was calculated. Capacity factor expresses the ratio between the actual electricity produced by a given power plant and the hypothetical maximum achieved if the power plant operates at full time. Capacity factor was used due to its dependence on the regime flow (Casadei et al. 2014).

The data to perform the analysis of the demand were collected from the results of PDIRT - Plano de Desenvolvimento e Investimento da Rede de Transporte de Eletricidade 2014-2023 (Development and Investment Plan of the Electricity Transmission Grid 2014-2023) (REN 2013), which introduces some changes to previous studies at national level, namely on the assumptions to design scenarios, based on recent data. For the fossil fuels prices (coal and natural gas), the data were obtained from UK National Statistics (Department of Energy & Climate Change 2015) as the information for Portugal is scarce, demonstrating their annual variation for the period 1990-2014.

Uncertainty analysis was conducted with @Risk program, from Palisade, which is a suitable tool intended to measure the risk related to a given decision. It resources to the Monte Carlo simulation, a widely used tool for analysing problems that involve many and potentially correlated uncertainties, allowing probability assignment for different future scenarios (Vithayasrichareon & MacGill 2012).

RESULTS AND DISCUSSION

Qualitative Analysis

In 2014, renewable energy sources (RES) technologies contributed to about 62% of the total electricity production (REN 2015). The integration of RES in the power system is the main driving force for Portugal to achieve global goals in respect to the reduction of GHG emissions. Figure 2 presents some RES contribution to electricity production in the last years. Wind onshore is, at some extent, a well-developed technology and, along with large-hydro (dams and run-of-river), is the major renewable technology contributing to produce electricity in Portugal. One aspect that deserves particular attention is the substantial integration of solar photovoltaic technology in the electricity matrix since 2007. In respect to mini-hydro technology, its integration is still very limited when compared with wind onshore or solar photovoltaic.

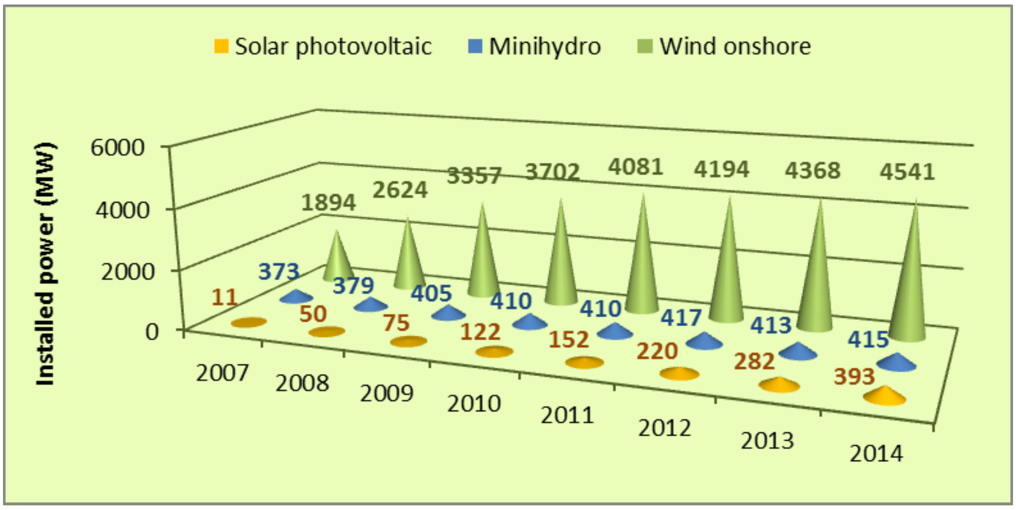

Figure 2: Installed power for electricity generation from technologies of variable output in Portugal since 2007, at the end of each year (own elaboration, data obtained from REN).

Despite its advantages to promote the desired sustainable pathway for Portugal, the integration of RES in the electricity system is perhaps the main challenge in long-term electricity power planning. The challenge is allied to the high level of uncertainty brought by intermittent sources. Intermittency comprises two different aspects: limited-controllable variability and partial unpredictability (Pérez-Arriaga 2011). Another risk factor that can increase RES related-uncertainty is climate change.

Future demand is one major uncertainty facing electricity power planning, since it is naturally driven by population growth and economy. National and global policies related with the promotion of a sustainable future, particularly the reduction of greenhouse gases (GHG) and the increasing awareness to energy efficiency, have led to changes in the use of electricity. Other factors may be underlying the transformations in future electricity demand, such as the climate change, which may cause an increase in the electricity consumption in summer season as a consequence of the increasing cooling needs. Figure 3 shows that the pattern of electricity consumption in Portugal is very similar in each year, particularly for peak months, but the demand has decreased in the last years, particularly since 2008. This shift in the electricity consumption may be caused by several factors, namely global economic crisis, high expression of the migration phenomenon and/or public awareness of the energy efficiency relevance. However this tendency cannot be forecasted into the future, since, for example, historical data have demonstrated a contradictory behaviour.

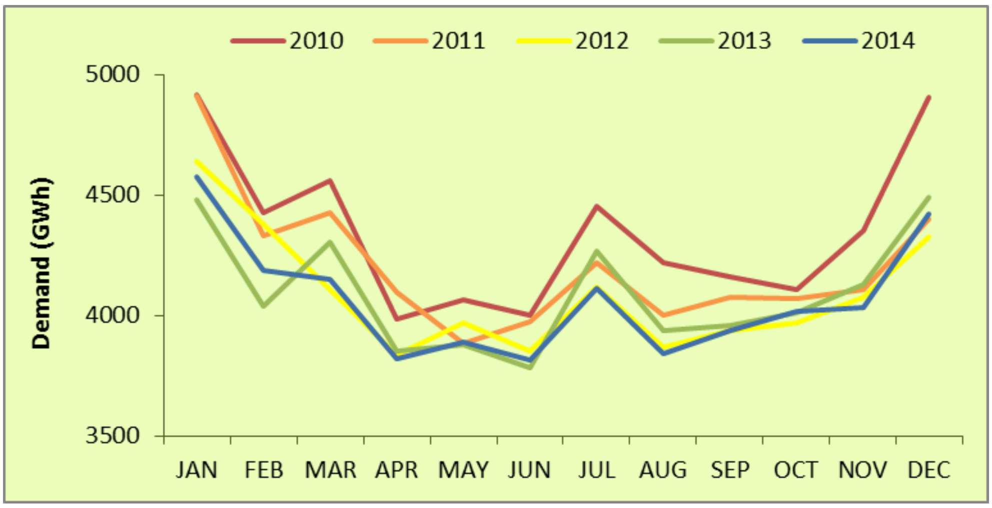

Figure 3: Monthly electricity consumption since 2010 in Portugal (own elaboration, data obtained from REN).

Finally, another factor that can bring high levels of uncertainty to the Portuguese electricity power planning is the fossil fuel prices. Portugal is totally dependent on the supply of fossil fuels (oil, natural gas and coal) from foreign countries, regardless it's notable efforts to reduce external dependency in the last years, as illustrated in Figure 4.

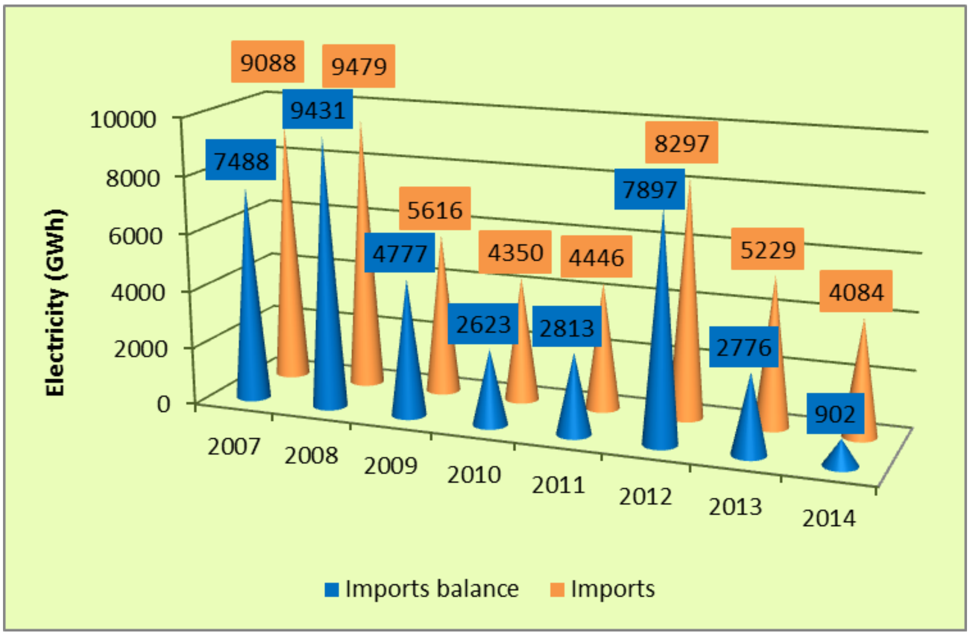

Figure 4: External dependency on fossil fuel for electricity generation and imports balance since 2007 in Portugal (own elaboration, data obtained from REN).

Quantitative Analysis

The data collected for the period 2007-2014, for each of the considered RES technology at each month, was adjusted to a pdf that better fits the time series. After the adjustment, a Monte Carlo simulation was run. As an example, the results for February for wind, solar, minihydro and run-of-river technologies are presented in Figure 5.

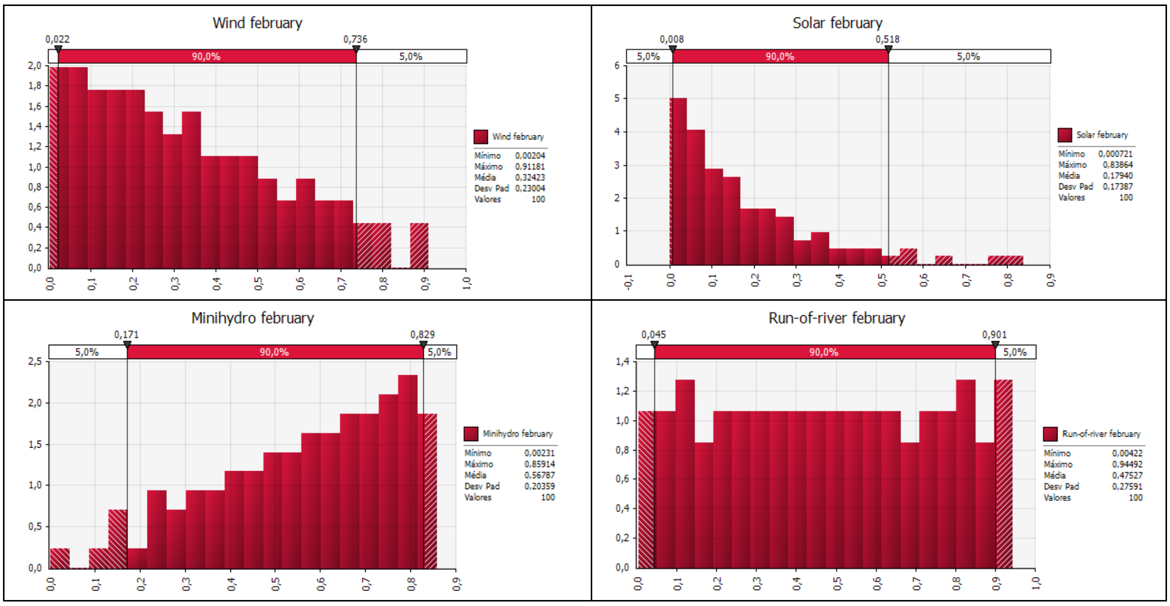

Figure 5: Probability distribution for each technology (wind, solar, minihydro and run-of-river, respectively), in February, resultant from @risk.

Each energy source displays a particular behaviour that is different between them and different at each month. This behaviour, related to the capacity factor of the respective electricity generation technology, can be translated into a pdf. For example, following Figure 4, in February, wind onshore and minihydro technologies exhibits a triangular distribution, while solar photovoltaic technology exhibits an exponential distribution and run-of-river technology a uniform distribution.

Table 1 shows the pdf that better fits each technology at each month. Wind onshore technology reveals a behaviour along the year that can be expressed as a triangular distribution from January to April and a BetaGeneral distribution the rest of the year, except during the months September and October for which a Gamma distribution is the best fit. As for solar technology, its capacity factor exhibits an exponential distribution during the entire year. Water-based technologies, namely minihydro and run-of-river, present miscellaneous distributions, varying from triangular, exponential, uniform, betageneral, Gamma, Weibull and Pearson.

Table 1: Probability distribution for each technology, at each month.

	Wind onshore	**Solar photovoltaic**	**Minihydro**	**Run-of-river**
Jan	RiskTriang	RiskExpon	RiskTriang	RiskUniform
Feb	RiskTriang	RiskExpon	RiskTriang	RiskUniform
Mar	RiskTriang	RiskExpon	RiskUniform	RiskUniform
Apr	RiskTriang	RiskExpon	RiskBetaGeneral	RiskUniform
May	RiskBetaGeneral	RiskExpon	RiskBetaGeneral	RiskBetaGeneral
Jun	RiskBetaGeneral	RiskExpon	RiskGamma	RiskTriang
Jul	RiskBetaGeneral	RiskExpon	RiskWeibull	RiskWeibull
Aug	RiskBetaGeneral	RiskExpon	RiskWeibull	RiskExpon
Sep	RiskGamma	RiskExpon	RiskPearson5	RiskTriang
Oct	RiskGamma	RiskExpon	RiskInvgauss	RiskTriang
Nov	RiskBetaGeneral	RiskExpon	RiskTriang	RiskTriang
Dec	RiskBetaGeneral	RiskExpon	RiskUniform	RiskTriang

The demand pdf is represented in Figure 6. The Monte Carlo Simulation was run considering a demand growth rate between 0.8% and 1.1% since a higher growth rate is not likely to occur in the future, as the energy efficiency society awareness is increasing and efficiency of electricity generation power plants is also increasing driven by learning rates and technology development.

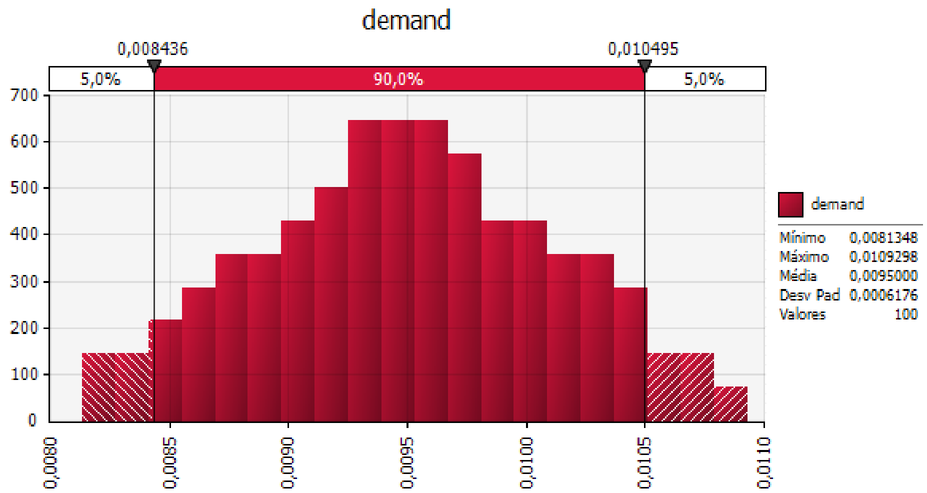

Figure 6: Probability distribution for the electricity demand.

The results for the fossil fuel prices are presented in Figure 7. Coal price follows an exponential distribution and natural gas price follows a Pareto distribution.

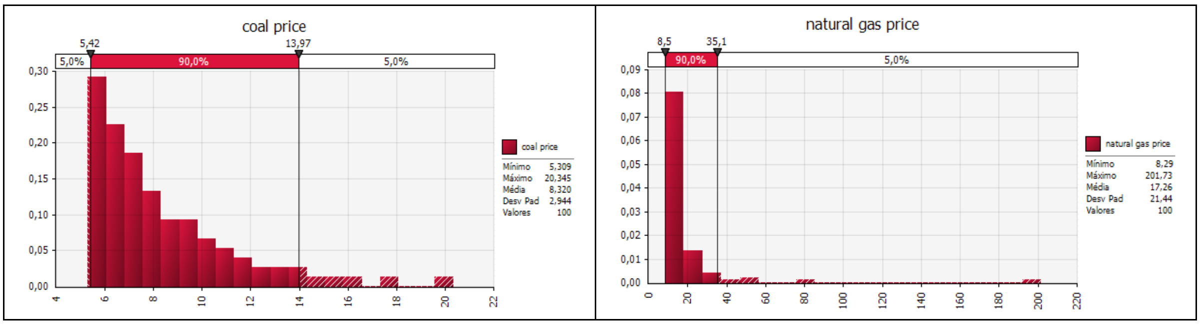

Figure 7: Probability distributions of the coal and natural gas prices, in €/MWh.

CONCLUSIONS AND FURTHER RESEARCH

Deterministic models are well-recognized in the electricity power planning field and are presented as a good strategy to develop long-term scenarios. However, deterministic models use assumptions of the future behaviour based on fixed parameters, as if the future is known. To deal with uncertain parameters, deterministic models use sensitivity analysis, and so, they are viewed as a useful simple approximation of reality, that is easier to build and interpret than stochastic models. On the other hand, stochastic models, instead of using deterministic values, identify uncertain parameters and assign to them probability distributions mapping their possible occurrences, turning into more reliable scenarios.

This work intended to analyse several uncertain parameters that could affect Portuguese electricity systems and that should be included in electricity power planning. For this purpose a literature review was made in order to identify the uncertain parameters that can influence the electricity generation system and then the Wilson matrix was used to prioritize the parameters. Each one of the selected parameters – sources of variable output for power generation, future electricity demand and fossil fuel prices – was qualitative and quantitative analysed. The qualitative analysis was carried out resourcing to literature and national reports review, while quantitative analysis was based on historical data or forecasts on national reports and makes use of @risk software. This program provided a distribution probability function for each uncertain parameter.

From this study it can be observed that several different behaviours for each uncertain parameter can be found along a time horizon. Thus, in order to obtain more reliable scenarios for future electricity system, the probability of the occurrence of each uncertain parameter's behaviour must be considered in the electricity power planning. The research is now proceeding with the inclusion of the results on an electricity planning model, aiming to design more realiable electricity scenarios under a probabilistic risk assessment.

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