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A methodology to incorporate risk and uncertainty in electricity power planning

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ABSTRACT

Deterministic models based on most likely forecasts can bring simplicity to the electricity power planning but do not explicitly consider uncertainties and risks which are always present on the electricity systems. Stochastic models can account for uncertain parameters that are critical to obtain a robust solution, requiring however higher modelling and computational effort. The aim of this work was to propose a methodology to identify major uncertainties presented in the electricity system and demonstrate their impact in the long-term electricity production mix, through scenario analysis. The case of an electricity system with high renewable contribution was used to demonstrate how renewables uncertainty can be included in long term planning, combining Monte Carlo Simulation with a deterministic optimization model. This case showed that the problem of including risk in electricity planning could be explored in short running time even for large real systems. The results indicate that high growth demand rate combined with climate uncertainty represent major sources of risk for the definition of robust optimal technology mixes for the future. This is particularly important for the case of electricity systems with high share of renewables as climate change can have a major role on the expected power output.

1. Introduction

Electricity is an indispensable good for society development and growth of a nation, stimulating the economic and technological development of a country [1]. 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 requiring short- and long-term electricity power planning and management decision making. All these problems have in common the need to reach solutions that minimizes the total system cost while meeting electricity demand at every time in the planning horizon. However, single cost minimization is no longer an acceptable objective and sustainability and resilience concerns are driving electricity systems to adapt and evolve, forcing to consider relations within society and environment, technology development and political goals [2]. These transformations had increased uncertainties in short- and long-term, bringing with it more complexity to the planning process and increasing uncertainty in the decision-making process.

One efficient technique recognized and used worldwide for energy planning is scenario generation [3]. 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 *a posteriori* sensitivity analysis, that allows determining which variable(s) influences most electricity power planning, uncertainties remain unquantified [4]. However, not properly considering uncertainties when modelling electricity power systems, and particularly the possible correlations between them [5], can turn seemingly cost-effective results into obsolete and inadequate options [6]. This is precisely the focus of this work, addressing the inclusion of uncertainty on the design of robust electricity scenarios. Although different uncertainties in the energy systems can be recognized including technical and economic ones [7], for the sake of simplicity this work will mainly address uncertainty related to operational parameters, namely

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demand and generation values in power systems, in particular renewable power output.

The main objective of this work is then to propose a methodology to incorporate risk and uncertainty in electricity power planning, supported on deterministic optimization models combined with Monte Carlo Simulation of uncertain operational parameters. The application of this methodology is deemed to be relevant for the design of generation expansion plans and for the evaluation of its robustness under uncertain operational conditions. The contribution of the paper is then twofold. Firstly, a methodology to deal with uncertainty in operational parameters is presented, particularly well-suited for systems with high renewable share. Secondly, the proposed methodology is demonstrated for an electricity system close to the Portuguese as an example of a system with high renewable integration and aiming to show the contribution of the approach to support robust energy decision making under uncertain future conditions.

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

2. Risk and uncertainty in electricity systems

The electricity sector is characterized by a high level of uncertainty and risk, resulting not only from its close relationship with an increasingly dynamic policy and regulatory framework but also from its high sensitivity to parameters such as climate conditions, economic environment or social perception. Important uncertainties and risk factors for electricity systems are presented in Table 1 proposing and describing 5 main categories and risk sources respectively.

Economic risk encompasses not only microeconomic aspects of the project, such as the uncertainty related to the fuel prices or business taxes, but also macroeconomic parameters, namely electricity market regulation and national economic growth [7].

Geopolitical risks are particularly relevant in systems depending on the external supply of electricity and/or fossil resources (coal, natural gas and oil). Political instability, between and within countries, may reproduce severe risks to the security of electricity supply, such as prices volatility, disruption of supply chains or degradation of international relationships [8]. Sociocultural risks are also permanently present when defining a plan or strategy for the electricity system, because local communities can create barriers to their construction or, on the other hand, encourage their development, according to their perception about different technologies [9]. The issue of social and cultural acceptance as important risk factors for the design of electricity plans and projects has motivated different works aiming to analyse the perception of population towards different energy options. Some examples include the studies on local communities acceptance of wind onshore power plants for Italy [10] and for China [11] or on the public opinion about the deployment of wind, solar, hydro and biomass technologies in Portugal [12].

Uncertainties in the energy sector driven by climate change and environmental constraints have gained attention in recent years as documented in many works [13–16]. A review of the vulnerability of the energy sector to climate change was conducted by Schaeffer et al. [13] 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. [14] 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 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 another study, encompassing the vulnerability of the Brazilian energy system to climate change, Lucena et al. [16] demonstrated its impacts on the hydropower generation and liquid biofuels production, and later, in the wind power potential [15].

Other studies have emphasised the technical uncertainties related to the large contribution of sources of variable output in the power systems, namely wind and solar power. Ludig et al. [17] analysed low carbon scenarios for the German electricity considering as uncertainties both the long-term electricity demand and the large-scale availability of offshore wind and CCS (carbon capture and storage) units. In the work of Pérez-Arriaga [18], the author examines the large scale penetration of intermittent renewables technologies in the electricity sector and its impacts on the system's operation and reserves requirements, flexibility and

Table 1
Uncertainties and risk sources in electricity systems.

Categories	Description	Risks and uncertainties
Economic	Risks arising from the financial aspects of the project, the market conditions and the economic growth of a country.	Project capital costs Commodities prices Operational costs Interest rates External costs
Geopolitical	Risks arising from political decisions of one foreign country affecting another country or region.	National policies International agreements Environmental regulation
Sociocultural	Risks arising from divergences on social and cultural characteristics of different communities.	Behavioural change Future electricity demand Social acceptance
Environmental	Risks related to the influence of the environmental conditions on the performance of the electricity system.	Extreme climatic events Climate change Natural accidents and catastrophes
Technical	Risks related to topological and operational conditions of the electricity system.	System's infrastructure Reliability of resources Learning rate Failures and forced outages