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Portfolio applications in electricity markets review: Private investor and manager perspective trends

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ABSTRACT

The private sector plays a major role in the expansion and operation of power systems in most countries, especially those running liberalized electricity markets. Policymakers have the task of inducing private agents, through their regulatory designs, to make decisions that point toward social welfare maximization. Conversely, it is a task of private agents to protect themselves against the risks of the sector, including regulatory risks, international fuel price uncertainty, climate change policies, natural resource availability, electricity demand uncertainty, CO_2 clearance prices, etc. Instead of hiding all of these risks within the total project costs and losing competitiveness, private agents can use diversification as a strategy to deal with them. This paper presents a review of the main applications, voids and challenges of portfolio optimization for two key agents of the private sector: investors and managers. The problem of the investor is to design a technology portfolio to invest in that maximizes its expected returns and limits risks, while the manager has to design a portfolio of financial/physical instruments (long-term contracts, futures, etc.) to sell/buy electricity and hedge against price risks. We have found two fundamental issues in the literature; the first and most important is excessive confidence in historical data and statistical analysis for predicting future price behavior for a changing future in detriment of more structural analysis. Structural analysis can include particularities of modern power systems such as future transmission changes, congestion, operational constraints (ramps), new entrants, new technologies, and new demand grow patterns that cannot be taken into account by simply analyzing price historical values. The second is the omission of renewable complementarities, which is a proven characteristic of dispersed renewable plants that may have important risk-mitigation effects, although it has largely been ignored in portfolio analysis due to insufficient data, modeling limitations, and computational complexity.

1. Introduction: portfolio optimization opportunities in the private sector

New problems arising in the modern era such as global warming produced by anthropogenic greenhouse gas emissions on one side, and our dependence on electricity on the other, point toward the integration of new and clean technologies into the grid [1]. The concerns about the environment have not only pushed technological development, but also new regulations seeking to limit local and global emissions. New technologies dependent on natural resources such as solar and wind farms, new, more stringent local and global environmental regulations, and the new market arrangements that are necessary to accommodate such changes are added to a global context where **uncertainty** is the common denominator [2,3]. The feasibility of big investments, such as new large power plants and new, high-capacity transmission corridors, hinges on the risk perceptions of market agents on a series of uncertainties at the operational, commercial, planning, and regulatory levels. The electricity system is now flooded with these uncertainties in multiple time scales, increasing the difficulty of decision making and pushing for the development of new risk management tools, which are fundamental for developing energy projects with limited levels of risks [4,5].

There are three key agents in the electricity sector who are constantly in need of risk management tools: private investors, managers commercializing energy (for large energy holdings, industrial consumers, or load serving entities) and planners, which are often specialized units of the regulator seeking social welfare over both the long and short run. The three interact with each other under the same platform, the energy markets. However, they face entirely different problems with respect to risk management.

The risk management problem for planners, for instance, often consists of long-term planning for the generation mix and transmission

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updates that maximize social welfare along with the policy design to achieve that plan. There are multiple sources of uncertainty including fossil fuel prices, renewable resource availability, technology development, social opposition, and global and local emissions limits, among many other factors that matter in these long time scales. The multiple sources of uncertainty notwithstanding, the vast majority of the literature over the last two decades has focused solely on fossil fuel price uncertainty [6–18]. Thus, the literature is paying limited or no attention to the other sources of uncertainties.

While market participants are key players in today's electricity sector, their risk management problems are less developed compared to the planner problem. However, after a decade of portfolio application for private agents, a systematic literature review is well justified by a number of important articles addressing diversification opportunities and efficient risk taking by trading in multiple markets in different time frames, investing in multiple technologies, and exploiting distant resources with non-coincident production connected to the transmission grid (temporal and geographical complementarity), etc. In addition, there are a number of new concepts, tools, and methodologies available in the literature that have not been fully integrated into private portfolio analysis such as complementarity assessment for multiple renewable sources, structural modeling of the power system physics, and the integration of real option analysis and portfolio optimization. This literature is reviewed in the following sections, highlighting research trends, opportunities, and challenges. Most of the key concepts found in the literature reviewed in this paper are summarized in Fig. 1. The key concepts appearing around the figure of the investor are option value, return and risk measures. Around the figure of the portfolio manager we found trading mechanisms, dynamic and multi-stage, static models, etc. We also found some key concepts around the literature dealing with both market agents, referred to here as cross-cutting issues, among these we are highlighting statistical price modeling, structural modeling, and renewable modeling. All of these concepts are briefly explained and referenced in this review.

Exiting articles are mostly focused on portfolio applications from the planner perspective. This is the traditional planning problem, where systems costs are minimized. Here, portfolio theory allows including the risks over such social solution, without specific attention to market details or market agents.

Given the current trends in power systems is every day more relevant considering the private agents´ perspective. The private sector has a growing role in power systems, especially in renewable energy development. This paper is focused on the perspective of private agents and its contributions can be summarized as follows:

- To the best of our knowledge this is the first review on portfolio applications focused on private agents (both investors and managers). This perspective is of growing interest due to the current trend of implementation of electricity markets across the world and increasing the deployment of renewable energy technologies.
- The paper presents an overview of different portfolio tools for the decision making process of private agents in power systems with high penetration of renewable energies.
- In addition to the review of the existing literature, this paper discusses cross-cutting issues emerging from the growing interaction of a new technological paradigm: markets and uncertainties sources driven by renewable energy development and technology evolution.

This paper is organized as follows: Section 2 provides an overview of the applications, problems, and challenges of portfolio optimization for **private investors**. Specifically, Section 2.1 presents the different measures of return/cost and risk typically covered in the literature, Section 2.2 highlights the lack of appropriate modeling of uncertainty factors that are usually ignored even when they play an important role for investors, and finally, Section 2.3 addresses the importance of considering the value of waiting in the investment decision problem and how to address it in a portfolio analysis. Section 3 discusses the main applications of portfolio optimization from the **manager's perspective** and presents two families of approaches: static and dynamic models. Section 3.1 presents static models that assume that all decisions must be made "here and now," and Section 3.2 presents dynamic models that are much more computationally demanding but they are able to separate "here and now" decisions and "wait and see" decisions, and finally, Section 3.3 presents alternative markets, such as capacity markets, demand response markets and others, to diversify services and mitigate risks. Section 4 presents cross-cutting issues, voids and challenges from both perspectives (investors and managers), Section 4.1 provides an overview of the most used modeling approaches to simulate price evolution, and Section 4.2 focuses on renewable profile complementarities and how they have been ignored by portfolio literature, even when there is literature available that provides estimations and measurements of high complementarity between geographically dispersed renewable resources. Finally,

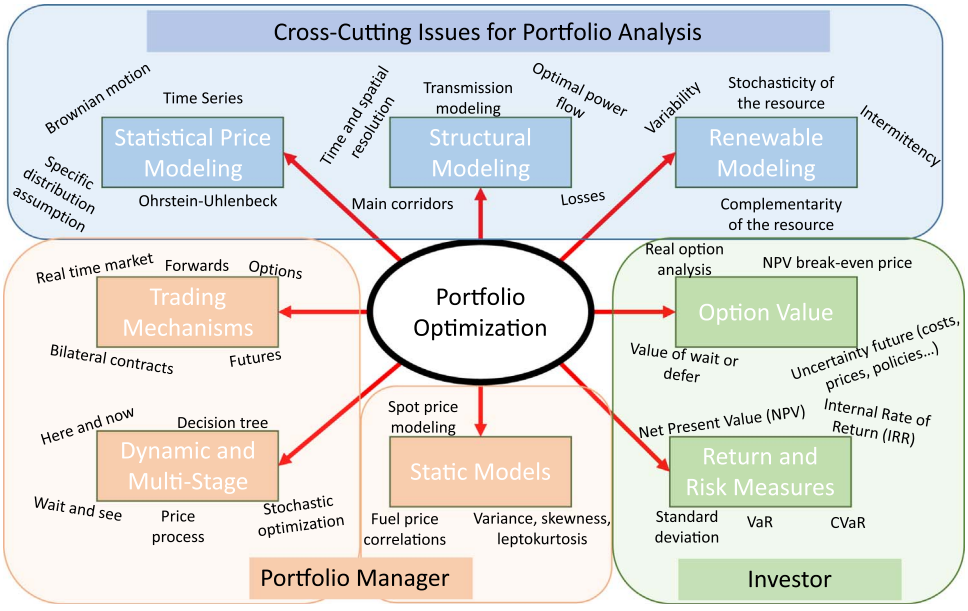

Fig. 1. Most important concepts reviewed in this paper.