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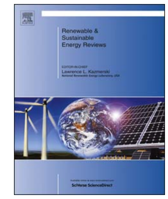

Financial risk reduction in photovoltaic projects through ocean-atmospheric oscillations modeling

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ABSTRACT

The impact of climate change on society has increased the interest to deploy renewable energies and to understand climate. Climate variability is partly predictable and is a fundamental factor in explaining financial risk in renewable energy projects. Current methodologies used for risk assessment do not appropriately account for climate predictability. We found limited literature on risk reduction on PV projects through the modeling of predictable components of solar radiation and ocean-atmospheric oscillations, allowing us to present original proposals to fill these voids. A new profit model for PV plants was developed, capturing this predictable climate information. The proposed methodology is potentially applicable to hydro, wind and other renewable resources, and allows leaving aside predictable climate components from the project's risk calculation. The model was tailored for the risk assessment of PV investments and is applied over 10 geographical areas across Chile, the largest PV market in Latin America, where climate is strongly affected by 3 ocean-atmospheric oscillations (El Niño Southern Oscillation, Southern Annular Mode, and Indian Ocean Dipole). Using the model in these regions allows reducing the monthly financial the risk to reduce by 60–81% compared to traditional methodology. For a 100 MW PV project located in those areas, this means reducing annualized risk from 4.93 to 7.88 MM $USD/year (traditional model) to 1.11–2.38 MM USD/year (proposed model). Modeling of ocean-atmospheric oscillations allows achieving the greatest risk reduction between the cities of Copiapó and Coquimbo (north-central regions), decreasing their influence towards the extreme latitudes. Their risk reduction will depend on the quality of the model, and may have strong implications for both investors and financial institutions. It could also impact competition in the energy sector due to possible asymmetries of information. To facilitate extending the use of the model elsewhere, the incorporation of subsidies is discussed.

1. Introduction

In recent years, photovoltaics (PV) have strongly penetrated the international energy markets at exponential growth rates, mainly driven by subsidies [1–7] and by strong and sustained reductions of PV cell costs [8,9]. Europe led the installation of capacity until 2011. Since then, incentives were reduced in Europe and the market shifted to China, Japan and USA (see Fig. 1). In 2014 China was the main installer with 10.6 GW of the 40 GW installed that year. Next in relevance where Japan with 9.7 GW, Europe with 7 GW and USA with 6.5 GW. However, all these markets sustained their growth (and explained their falls) due to subsidies and supporting policies [10].

1.1. Financial institutions' and investors' risk perception

Despite impressive growth, photovoltaic systems face various barriers to their development in several countries. These barriers commonly relate to the variability and risk of their generation. A large literature body tries to manage this variability through technical complementation with other resources such as batteries, hydroelectricity and wind generation [11–13]. Equally important, but less present in literature, is the difficulty to obtain financing, since financial institutions perceive solar projects as riskier than conventional ones [14], a situation that this work aims to challenge.

Modern Portfolio Theory (*MPT*) developed by Novel Markowitz [15] assumes that the investor is risk averse and therefore prefers - from a set of different asset portfolios with equal expected profits - the one with the least profit variability. Beyond the purely financial world, this theory has been applied to real assets, particularly to energy projects. For example, *MPT* has been used multiple times to prove the ability of renewable energies to diversify energy sources and to improve energy security [16–23].

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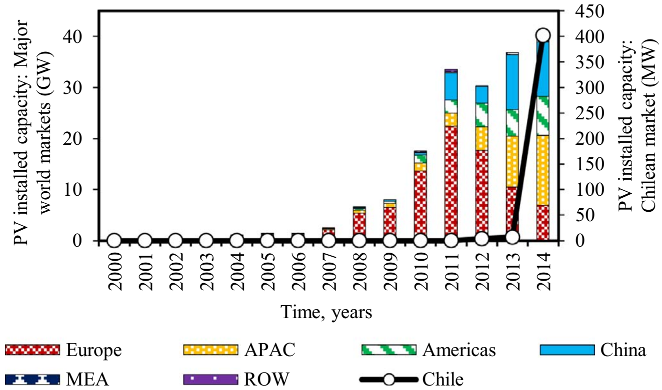

Fig. 1. Photovoltaic annual installed capacity for major regions of the world [9].

1.2. Review of solar radiation and ocean-atmospheric oscillations in PV project's risk

Our bibliographic review takes a different and complementary path from *MPT*. We revised the literature related to the impact of predictable solar radiation and ocean-atmospheric oscillations (such as El Niño Southern Oscillation, *ENSO*) on the reductions of the investment risk of a single PV project before its inclusion into a portfolio. Existing voids in the literature are identified and original propositions are made when necessary.

The Chilean market was selected as a case study due to its outstanding solar potential, its booming solar PV market and its exposition to the most energetic ocean-atmospheric oscillation (ENSO), which affects the USA as well as several counties in Asia, Africa, Australia and the rest of America [24,25].

1.3. Relevance of the Chilean PV market

Chile now attracts international attention not only because it has the highest solar potential in the world, but also because it has become a precursor to unsubsidized markets, marking a turnaround. Chile is already the largest and fastest growing PV market in Latin America. The accumulated installation of photovoltaic systems in Chile has soared, growing from 6 MW in 2013 to 536 MW in 2015, expecting to reach 1 GW in 2016. Future growth is supported by more than 9 GW of projects approved by the environmental assessment system, which are competing to be finally developed [26]. This trend - which is driven without any public policy aid[1] by Chilean unique solar radiation and high electricity tariffs - may be followed by other markets if the cost reduction continues. According to the "Solar Power Europe" association, 5 GW are expected to be installed in Chile by 2019, which will position it as the main pole of solar development in Latin America [10].

1.4. Structure of the article

This article is organized as follows: Section 2 reviews the available literature related to the impact of predictable solar radiation and ocean-atmospheric oscillations on the reduction of the investment risk of a single PV project. Section 3 highlights voids present in the literature regarding climate predictability and PV investments. In Section 4 a monthly profit model for investments in PV projects is proposed, specifically designed for financial risk assessments. In Section 5 the importance of the Value Of Information (VOI) on partly predictable climate data for PV projects is highlighted and the use of variance decomposition to withdraw predictable components of profit from risk is explained. Section 6 shows and discusses Chilean Solar radiation resource, which is used for the case study developed. Section 7 reviews the three main ocean-atmospheric oscillations affecting Chilean climate along with their associated indexes and dynamics. Section 8 develops a predictive profit model that incorporates solar radiation and ocean-atmospheric oscillations. Section 9 presents the risk reduction achieved due to climate predictability for the selected case study (Chilean market) in 10 geographical zones. Section 10 extends the profit-risk model proposed for PV projects by including subsidies and discusses the potential impact of larger penetrations of renewable generation on the Chilean market driven by the risk reduction. Finally, Section 11 offers a conclusion to this study.

[1] Chile has a market share incentive for renewable energies, but it has been overpassed largely since 2011 [26].

2. Review of the impact of predictable solar radiation and ocean-atmospheric oscillations on the reduction of the investment risk of a single PV project

Climate change has deepened the interest to deploy and encourage renewable energy generation around the world. Ironically, climate itself is one of the key barriers to obtain financing for renewable projects because financial institutions perceive solar projects as riskier than conventional ones. Climate change concern has also renewed the interest in understanding climate variability to predict and mitigate its future impact on society. Thus, growing interest has emerged regarding ocean-atmospheric oscillations (which are ocean-atmospheric climate anomalies) such as *El Niño Southern Oscillation* (ENSO), which impacts some regions of the planet with irregular periodicities of years or decades.

Despite the interest on climate and its evident impact on PV project risk, an extensive review of literature conducted as part of this research found no studies relating PV risk and climate and very limited literature on some other related subjects. In order to understand and detect the voids present in the literature, an extended review was conducted on key aspects that would finally enable the calculation of the financial risk reduction on a utility-scale PV project due to information contained in climate (solar radiation and ocean-atmospheric oscillations). This extended review allowed us to propose some original contributions that are included in this study. The main topics of this extended review are detailed in the following subsections:

2.1. Review view of PV yield models for the long and short term

PV generation systems have nonlinear components (e.g., solar panels and inverters), nonlinear relations between components (e.g., inverter ratio) and nonlinear relations between radiation and ambient temperature [27–30]. The strong presence of nonlinearities explains that in the short-term most publications of PV electricity production models use very detailed nonlinear relations between generation and radiation. Some common topics related to short-term production are energy management, regulation of netbilling/netmetering, statistical calculation of operational parameters and the short-term climate prediction (of a few days) (energy management [31]; regulation of netbilling/netmetering [32], statistical calculation of PV plant's operational parameters [33–35] and the short-term climate prediction [36,37]).

On the contrary, most studies of PV power generation that model the long-term use simple linear relationships between radiation and production. Within these linear models, most common topics are planning, market regulation, sizing and performance evaluation. (Planning [38,39]; market regulation [40]; sizing [27,41–43], PV plant and PV panel performance evaluation [44–47]). The studies of Wild [39] and Huld [46] are exceptions focusing within the long-term modeling, since these include logarithmic relations between radiation and temperature in PV panel efficiency models.