DIRECT INVESTMENTS IN RENEWABLE ENERGY PORTFOLIOS: STOCHASTIC NPV-BASED CAPACITY BUDGETING

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Overview

In the electricity sector investors are exposed to a considerable amount of risk which mainly arises due to uncertain future cash flows, i.e. uncertain electricity prices and uncertain fuel/carbon prices (Tietjen et al.,2016). When it comes to evaluating investment opportunities in renewable energy sources (RES), uncertain production volumes associated with the intermittent character of RES are sources of uncertainty that have to be taken into account in investment decision. In renewable energy investments, where operational costs are rather neglectable, the risks of variable costs are therefore replaced by the risk of the RES availability. Modern portfolio theory (MPT) has emerged as a widely accepted methodology to account for risks in capital budgeting problems under uncertainty. Based on the seminal work of Markowitz (1952), MPT has been applied in various energy economic related problems, e.g. determining the optimal generation expansion portfolio by specifying a tradeoff on return and risk of the investment opportunity. In the MPT context, uncertain parameters are assumed to be normally distributed, which is a strong assumption limiting the applicability of the model. Moreover, when the model is calibrated with highly granular data, e.g. hourly data of the power available, estimating parameters might become infeasible. Reducing the granularity of the data in the model by e.g. considering averaged values of the daily power available increases feasibility of parameter estimation but comes at the expense of information losses, i.e. neglecting auto-correlation structures. In this paper we present an alternative data-driven framework to determine optimal investments in renewable energy technologies under uncertain production volumes and uncertain electricity prices.

We use a stochastic Net-Present-Value (NVP) based model for solving the investor's capacity budgeting problem, where optimally installed capacities in renewable energy technologies are determined. We consider an investor, who aims at finding the optimal level of investment in RES within the "Minimum exceedance probability (MEP)" framework. In the MEP framework, the investor introduces a probabilistic constraint to evaluate the profitability of the renewable energy portfolio, by requiring that the probability to obtain a NPV larger than a pre-specified threshold has to exceed an ex-ante specified confidence level. As there are several investment opportunities that fulfill this requirement an additional criteria has to be added for deriving the optimal solution. For this purpose the criteria of minimal capital expenditures is taken.

Methods

In the MEP framework, we model the investment problem via the probabilistically constrained optimization (PCO) paradigm, which was first introduced in Charnes and Cooper (1959). By modeling the profitability of the investment via a probabilistic constraint we introduce a different risk measure (the Value-at-Risk) compared to the variance in the mean variance portfolio approach. The modifications of Markowitz's capital budgeting model are needed as in the direct investment domain the size of the investments is no longer fixed by the investor's initial wealth, but the investment levels have to be determined explicitly subject to a budget constraint. For numerically solving the underlying PCO problem, the "Scenario Approach" of Calafiore and Campi (2005) is used. The numerical approach to the PCO problem is data-driven so that no NPV distributions have to be assumed. Forurthermore, the "Sample and Discard" algorithm (Campi and Garatti, 2011) is applied to reduce conservatism introduced by the numerical procedure and therefore trades feasibility and optimality. The obtained solution depends on the specified discard algorithm. However, in the light of Simon's "Satisfycing" theory, we do not take into account different discard algorithms but consider the solution associated with a special discard algorithm based on the marginal costs, which is also stated in Calafiore (2010) and applied in Ondra et al. (2021) to solve the probabilistically constrained generation expansion problem from the prosumer's point of view.

Results

We demonstrate the MEP framework by applying it to a use case, where the investor faces the “here-and-now” decision to invest in wind and solar renewable energy technologies and also determines the optimal generation mix. We sample from real-world output data of wind speed and solar irradiance for a typical location in Central Europe and use electricity spot market data from EXAA. By solving the probabilistically constrained investment problem, the investor obtains the optimal level of investment in renewable energy portfolios as a function of the required confidence parameter to exceed an ex-ante imposed threshold on the NPV associated with the investment opportunity. The investor not only determines the optimal level of investment in RES but also the optimal renewable energy portfolio, i.e. the optimal mix in the generation technologies. In contrast to standard Markowitz portfolio theory, we propose a pathwise approach where the sample-paths over the expected useful lifetime of the energy park also include the underlying auto-correlation structure of wind and solar power. We use blockbootstrapping to generate samples that replicate both short and long-term weather trends which allows for a more realistic modelling approach. In this framework we combine the essential features of (i) Martkowitz portfolio approach being an optimization framework and (ii) Monte Carlo analysis which allows to analyze characteristics of the underlying distribution of the stochastic NPV rather than reducing the properties to the first and second moment. We obtain for an expected lifetime of the energy technologies of 25 years, that the investor chooses a single renewable energy portfolio that consists only of wind power. This is due to the fact that in the nighttime no solar power output is available that can generate revenues. In order to obtain diversified renewable energy portfolios, power output from solar technology has to be subsidized.

Conclusions

This paper presents a data-driven decision support system to analyze the capital budgeting problem, which is restricted by a profitability requirement in terms of a probabilistic constraint from a private investor’s point of view. We thereby, apply the “Minimum exceedance probability” framework to the investment problem in renewable energy portfolios. By using a data-driven approach to solve the stochastic optimization problem we obtain distribution-free results. Therefore, no specific distributions on the uncertain parameters have to be imposed which increases the applicability of the model. In the use case, we demonstrate, that properly diversified renewable energy portfolios in wind and solar technology can only be obtained, when solar technology is subsidized. In this case, the optimal generation mix depends on the required confidence parameter and shifts towards solar technology for increased required reliability. Therefore, also in case of subsidized investment in solar technology, the optimal renewable energy portfolio depends on the investor’s specific attitude towards the threshold profitability and the required confidence parameter.

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