The portfolio perspective in electricity generation and market operations

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***Abstract*— Selecting portfolios of electricity production assets, energy sources and market participation strategies facilitates usage and management of complementary resources. It helps also power producers to address uncertainties and to balance profit contributions, costs and risks. Therefore, portfolios should be composed wisely. Our paper will bring concepts of portfolio optimization closer to private energy producers. We highlight important aspects to be considered and outline key value drivers. However, we call also for critical thinking if portfolios of physical assets should be considered a panacea to address uncertainty in power generation and market operations. An example demonstrates that, sometimes, financial instruments rather than diversification into renewables may prove more efficient to hedge risk. In addition to the possibility of hedging through the portfolios, portfolio management can yield benefits for internal physical balancing and market access – but the value in terms of additional profit and risk reduction depends on market conditions.**

***Index Terms*-- Portfolio optimization, Uncertainty, Risk, Electricity generation, Electricity markets**

I. INTRODUCTION

Producers of electric energy need to plan both investment into, and operation of, their generation assets and how to operate in the electricity market. However, they are rather heterogeneous, and vary from owners of single plants or wind parks, via owners of several similar plants or technologies, to owners and operators of a diversity of assets (both in technology and capacity), such as cascaded hydropower plants or a combination of wind and solar plants. They may have access to a single energy source or to a wealth of sources, with varying controllability, intermittency and storability – and, hence, vastly different profit contributions. They may be independent businesses or part of utilities, with a variety of goals. They may also differ with respect to market aspects, ranging from purely local to cross-national operators. This entails access to a variety of physical (such as day-ahead and intra-day markets) and financial markets. Some operators may participate in capacity, ancillary services or regulation services markets to improve profitability and diversify risks [1].

Consequently, a private investor or power producer may face questions such as: How may properties of the different energy sources be utilized in an optimal way? Are there gains in being well-diversified, in operating a portfolio of plants with different technologies and fuel sources rather than single plants, or in operating a portfolio of N+1 plants rather than one of N plants? Should market activities and production plans for various plants and technologies be coordinated or not?

This portfolio perspective includes coordinated planning for power generation, market operations, risk and risk management, maximizing expected return and simultaneously minimizing risk. It has been studied in a vast body of literature. One strand is based on modern portfolio theory, the mean variance model introduced by Markowitz in 1952 [2]. Here we find, for example, [3]–[5] while, among others, [6]–[8] represent approaches with a somewhat different risk valuation. On a system level, the portfolio approach is the standard one to handle essential balancing of production and demand. Different technologies (wind, solar, hydro, nuclear, coal, gas) have different cost structures and flexibility properties. Hence, to supply sufficient energy at the lowest possible total cost, often a mix or portfolio of technologies is optimal. Traditionally, base load has been supplied by nuclear and coal fired units or other technologies with very low operating costs. Peak load is supplied by gas-fired units more expensive both to install and to operate [9].

Recent applications of portfolio optimization in the private sector, for both investors and managers, are reviewed extensively in [1]. In this review, the authors point out that most proposed models are information demanding and have long run times. However, the dynamics of the markets and time constraints on making decisions call for decision support that is simple to use and allows for repeated runs with altered assumptions.

In this paper, we seek to discuss motivations and highlight some typical aspects of portfolio optimization for private energy producers, but also call for critical thinking on the appropriateness of the methods. Section II is dedicated to explaining how portfolio optimization for electricity generation and market operations may create value for private investors and producers. The example in section III underlines the importance of including the financial market when performing portfolio analysis. It shows that diversifying into renewables may not be as efficient as desired with respect to risk hedging, and financial instruments may prove a more valid approach. Section IV brings our arguments together in some concluding remarks.

II. THE VALUE OF PORTFOLIO OPTIMIZATION

Coordinating power generation and, thus, optimizing the generation portfolio can enhance profitability and mitigate risks. The motivation for performing portfolio optimization can be discussed through four main contributors: 1) access to information; 2) physical balancing; 3) market imperfection and 4) risk management. These four categories are illustrated in Fig. 1. In this section, we will explain and discuss these aspects in more detail. The categories are not independent of each other, and certainly the extent of market imperfections will highly influence the value and importance of portfolio optimization for all other categories.

Figure 1. Main benefits to be gained from portfolio optimization

Access to information

From standard economic theory it is well known that access to information can affect competitive strength and, therefore, have a value. Access to information can reduce uncertainty and risk, increase efficiency and give a competitive advantage. A diversified portfolio (in terms of production technologies or geographical location) can provide additional information with regard to forecasts for production levels from wind and solar power. The portfolio approach can also be motivated through access to information regarding linked production assets as an example from hydropower production shows. In a river course with multiple power plants, the inflow of water in downstream plants depends on the discharge decisions made upstream. Therefore, knowing the production schedules of upstream plants reduces the uncertainty about water availability downstream and can improve resource utilization. Therefore, access to upstream production schedules can motivate partial ownership in upstream plants.

Investing in an alternative technology can also be motivated by gaining insights that improve the ability to predict system and market behavior. For example, improved ability to forecast wind generation can impact scheduling of gas-fired power plants, as discussed in [10].

Physical balancing

Balancing the production in multiple plants might improve utilization of the production resources and thereby give portfolio gains. This is evident in the hydropower example from the previous section. Including all plants in the river course in the same portfolio enables coordinated scheduling to optimize the overall profitability of the river course. For instance, allowing upstream dispatch to adapt to downstream capacities reduces risk of spillage in small downstream reservoirs.

Literature shows a range of examples where the complementarity of different plants and technologies is utilized for balancing a portfolio. Hydropower proves particularly favourable in this regard. Facilitating fast regulation, it complements well, e.g., wind and solar power. For the Spanish system, [11] show positive effects of combining hydro- and wind power generation, most likely due to market imperfections and significant penalty costs for insufficient deliveries. Cooperation between wind and hydro-pump storage power producers has been investigated by [12], exploiting synergies between the technologies to mitigate wind imbalances. More recent research investigates coordinated planning of renewable and thermal power generation, typically on a more general, supply-oriented level. Effects of coordination between thermal-power dominated and hydropower dominated areas and consequences for the value of variable renewables are explored in [13].

Temporal dependencies in the production, such as start-stop and ramping constraints in thermal power production call for coordination of several producers in order to be able to respond to changes in power delivery. Increasing shares of variable renewable energy sources (VRES) production may entail more frequent start-stop operations and thus higher start-up costs in the thermal sector [14]. Some start-stop plans may even be technically impossible to implement, requiring a solution via market measures or through a portfolio of several generation plants or technologies. When market mechanisms ignore these costs or possibilities to hedge against unplanned starts and stops, non-market measures are needed to minimize negative effects of increased intermittence.

Market imperfections

With a liberalized market as, e.g., in Europe, the market represents the main coordinating mechanism. In principle, a perfect market will render portfolio optimization worthless for profit enhancement, as optimizing each individual unit according to the market signals should give the same result [15].

In reality, however, there are market imperfections that can motivate portfolio optimization.

Traditionally, electric energy has been the main product traded in the electricity system, while storability and controllability were an inherent property of the production technologies. Increasing shares of VRES, such as solar and wind power, challenge system balancing due to their intermittent character, making storability and controllability, or flexibility as a collective term, scarce resources. Unless such resources are properly priced and remunerated in the market, a flexible producer can be better off by including VRES in his own portfolio to extract the value of his flexible resources. Similar arguments can be made for ancillary services, such as reactive power and inertia, that are needed by the transmission system and where different technologies have different capabilities.

The argument can also be turned around, seeing it from a VRES producer's perspective. Producers are responsible for balancing own production and market position, which is a more or less impossible task with only intermittent production capacity, causing imbalance costs to be a main concern. Two effects can be achieved with a portfolio approach to remedy this challenge: increasing the portfolio with spatially distant plants to smooth out the effect of local weather variations and to ease VRES forecasting, or complementing the VRES portfolio with a flexible facility to balance the unpredictable VRES production. The portfolio gain from these approaches would depend on the alternative options for short-term rebalancing in the market and on how imbalances are penalized. With efficient market pricing of rebalancing products, there might be no portfolio gain for the producer.

Risk management

Companies and investors conduct risk management to stabilize their cash flows and stay solvent through fluctuations in markets and the operational environment. There is no standard approach to measure and manage risk, and several approaches are applied in the power sector.

To avoid undesirable decisions, [6] proposed a dynamic stochastic model for the power system expansion problem with a regret term added. Conditional value-at-risk (CVaR) addresses the risk of the portfolio incurring large losses [16] and has been applied, for example, in [17] together with a risk aversion factor and in [12] to maximize profits and to hedge against risks. In contrast, mean variance portfolio (MVP) approaches [2], exploiting the risk-reducing effects of diversification through a portfolio, offer a link to the market value of risk. According to [18], seminal literature on MVP applications in the power sector typically focused on fuel-price risk and generation costs and included only power sector assets. However, [3] show that adding photovoltaics and other fixed-cost-only technologies to a portfolio of conventional generation technologies can reduce overall portfolio costs and risk. Using Japan as a case, [19] discuss portfolio approaches including renewables such as wind and solar power. Their set-up takes into account CO_2 emissions as well as policy requirements such as a minimum share of renewables. Analyzing the European generation mix projected for 2020, [5] include also negative externalities such as total CO_2 emissions. Early MVP approaches adopted a social welfare maximization perspective on system level, but with increasing liberalization work on the perspective of a private investor seeking maximal profit has gained momentum. A growing number of contributions combines this perspective with portfolio approaches including electricity markets with physical and financial contracts. For example, [18] apply an MVP framework to analyze plant returns risk and investor incentives in liberalized electricity markets, maximizing investor returns for given risk levels.

III. FINANCIAL INSTRUMENTS

While the previous section emphasized the risk reducing potential in portfolio thinking through diversification, financial markets open for hedging with financial instruments as an alternative approach to risk management for private investors and producers. In many electricity markets, there is a market for long-term contracts for buying and selling power that can be used to offset risk in a generation portfolio. For the nearest horizon, up to a couple of years, this can take the form of a market for financial instruments such as futures, forwards and swaps. Beyond this horizon, the market is less transparent and contracts may be negotiated from deal to deal.

The convenience of jointly deciding contractual involvement and generation schedule of power producers is significant [17]. However, building on the argumentation in [15], a two-step procedure may prove more advantageous when financial markets exist: First, power generation is scheduled such as to maximize market value. Then, given this optimal production strategy, a set of contracts (a trading strategy) is found to minimize the risk of the total portfolio. It should be remarked that contributions in the literature typically do not evaluate the improved market value of a firm conducting (single step) integrated risk management compared to simply maximizing the market value (the first of our suggested steps). What is usually seen, are examples of how decisions change under different assumptions on risk aversion and distribution of outcomes.

It is quite common to argue to utilities that investing in renewable sources will diversify the generation portfolio and reduce risk, as explained in Section II. Consequently, the diversification argument is used to leverage low or even negative profitability of renewables projects. However, if a financial market is available, risk could be hedged more cheaply using contracts. We demonstrate this with an example.

Illustrative example

We consider a generation company that has mostly thermal assets, with an electricity generation of 100 TWh/a. Suppose electricity prices now are 30 €/MWh, and that the future holds two possible states: high price at 34.5 €/MWh (at a risk-neutral probability of 0.506) or low price at 28.5 €/MWh. These prices represent per unit energy produced revenue for the generation company in perpetuity. Since production costs are related to thermal fuel, unit costs are positively correlated with prices, 31 €/MWh in the high-price case and 29 €/MWh in the low-price case. The interest rate is set at 5%. We assume that the decision maker is concerned with downside risk and measure risk as the difference between expected and low-price case Net Present Value (NPV) – the smaller this measure of risk is, the better.

The annual profit consists of the revenues and costs from the thermal generation, such that, in the high-price case, the NPV is (34.5-31) * 100 / 0.05 = 7 000 million € and -1 000 million € in the low-price case. This gives an expected NPV of 3 048 million € and a risk of 4 048 million €.

Part 1. Adding a wind park to the generation mix

The company has the opportunity to invest in a wind park at a cost of 2 200 million €. Wind generation is correlated with price, giving 3.0 TWh/a in the high-price case and 4.0 TWh/a in the low-price case. The annual profit includes now the revenues from the wind park, 34.5 * 3 / 0.05 million € in the high-price case and 28.5 * 4 / 0.05 million € in the low-price case. Then, the NPV is (including investment in the wind park) 6 870 million € and -920 million €, respectively. The expected NPV is, hence, 3 022 million €, giving a risk of 3 942 million €. That is, the NPV is slightly lower when wind is included but this could be justified by the reduction in risk and, thus, vindicate a wind investment. However, this calculation does not prove that the wind park integration would be the cheapest way to achieve the risk reduction.

Part 2: Adding financial instruments

We assume that there is a contract available on the financial market that gives a payoff depending on the difference between a forward price of 31.54 €/MWh and the high or low prices that could prevail. That is, the forward contract is priced so as to give no expected gain at risk neutral probabilities, resulting in a payoff of -2.96 €/MWh in the high-price case and 3.04 €/MWh in the low-price case. The net present value of entering the contract, by either shorting or going long, is zero.

We now consider the strategy of using the contract to eliminate all risk. This calls for a short sale of 1 333 TWh, giving a hedge value (NPV) of -2.96 * 1 333 = -3 951 million € in the high-price case, and of 4 047 million € in the low-price case. Now the NPV of the whole portfolio is 3 048 million €, independent of the price outcome. The risk is then zero. This case is extreme because the company needs to short sell a large volume that, in reality, will affect the contract price. However, the hedge can be executed at a lower scale and still our point will be valid: risk will be reduced more than with adding wind and at zero change in the NPV of the portfolio. The reader can verify that a forward sale of not 1 333 TWh but just 35 TWh or greater will reduce risk more than investing in the wind park.

IV. CONCLUDING REMARKS

In this paper, we have presented an overview of literature on portfolio optimization for power producers. Additionally, we have discussed motivations for portfolio optimization and highlighted typical aspects relevant for private energy producers. By means of an example, we have also demonstrated that critical thinking on the appropriateness of the methods is important, in particular with respect to handling financial risk. We have shown that the presence of a financial market for hedging risk may make energy company managers pause when looking at risk-return tradeoffs for renewable investments. If financial contracts for hedging are available, the diversification argument for investing in renewables can be eroded. The policy implication is that the diversification argument should not be taken at face value when considering investment in renewables. There can be many reasons for engaging in the renewables business, but the risk-reduction argument should be scrutinized, even rejected, as a basis for investment decisions in many cases. It is, however, important to note that this conclusion strongly depends on an efficient financial market.

The motivation for performing portfolio optimization can be categorized into four main contributors: 1) access to information; 2) physical balancing; 3) market imperfections and 4) risk management. These categories are interlinked, and the contribution from each of them to the overall portfolio value will highly depend on market design, regulations and maturity. In terms of maturity, both the number of participants, the total liquidity and the liquidity for each trading hour will be important to understand how valuable a given asset in a portfolio, and the portfolio as a whole, will be. It is of particular importance to understand the market imperfections and how they may affect the value of the portfolios. If the markets were perfect, portfolio optimization would not provide an opportunity for profit enhancement, as optimizing each individual unit according to the market signals should give the same result. Characteristics such as unevenly distributed information and properties of the physical production systems (for instance, start and stop costs for thermal plants), contribute to the market falling short from efficient solutions and provide a potential value for portfolio optimization. In addition to potential profit contribution, there may also be other motivations for adding assets to a portfolio, for example, they may be of strategic nature, helping to enter a new market.

The rapid increase of production capacity from variable renewable energy sources creates a need for dynamic markets and increases the value of flexibility in the energy system. A portfolio perspective, in terms of both generation assets, flexibility sources (such as energy storages, flexible consumers and flexible generation assets) and multiple markets may provide substantial economic gains for power producers. Whether or not there is a potential economic gain, will depend on market design, regulations, liquidity and the other participants in the market.

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