1 Introduction

As evidenced in many reports of the International Energy Agency (IEA), by 2030 power consumption in the world will be twice as much as the current level at the end of 2009. While in Asia the need for investments in generation capacity is driven by the soaring demand for electricity, the growth-rate in Europe is rather moderate. However, huge investments in generation capacity are still required, as the European power plant park is aging. Most of the power plants, which were built up during the 1970s have to be replaced shortly.[1] Energy market experts predict that the investments for replacements amount to between 300 and 600 GW of installed generation capacity in Europe.[2] Indeed, most of the thermal power plants from German utility firms are already older than 30 years which requires replacements of 40 GW until 2020.[3]

As a consequence, investments in generation capacity are necessary in order to provide a reliable supply for customers. The liberalization of electricity markets, however, has changed the European market structure and therefore shifted these issues from a country basis down to a firm level.

1.1 Motivation

Liberalization goes along with increased competition and uncertainty, which requires European utility firms to adapt their business strategies.[4] Alongside the demand for replacements of power plants, tightening environmental standards force utilities to reassess their generation mix and investment planning. Even though a shift in utilities' fuel mixes towards low-emitting electricity power plants is very likely, new conventional thermal power plants are still needed. The volatility of electricity generated by renewable energies as well as a lack of power storage require a back-up from reliable, steady, quick and flexible sources such as conventional power plants. Hence, from a utility's perspective different power plant technologies do exist with individual merits very similar to ordinary financial assets. However, the issue arises of how utilities should combine different power plant technologies.

[1] See IEA (2008a) pp. 88-89.
[2] See Weber/ Swider (2006), pp. 1-2.
[3] See UBA (2005), p. 107.
[4] See Dyner/ Larsen (2001), pp. 1145-1154; Felder (1996), pp. 62-67.

Power plants are real assets and as a consequence the power plant park of a utility firm equals a portfolio of different generation assets. Hence, utilities operating a power plant efficiently in terms of return and risk are better off compared to competitors. Traditional capital market theory might assist to solve this trade-off.

1.2 Previous research

Mean-variance portfolio theory originally refers to the work of *Markowitz* (1952, 1959) who has developed the first analytical framework for selecting financial securities to optimize portfolios. Meanwhile such theoretical frameworks have been established in different business fields. In particular the Markowitz approach has become a useful instrument for appraising the return and risk for energy investments.[5] In the following section previous research will be briefly introduced.

Related research can be distinguished in two major fields. While the first group explores the national generation mix of an economy (henceforth: *macro level*) in terms of efficiency and social welfare, the second group studies the efficiency from an investor’s or company’s perspective (henceforth: *micro level*). The former has spurred extensive research during the time period before liberalization and therefore the interest in cost efficient energy supply from a welfare perspective. However, the structural change by opening European electricity markets to competition in the last decade has caused a need for further research by taking the micro level perspective. In addition the introduction of the European Emission Trading Scheme (EU ETS) will force utility firms to reassess their investments in generation capacity and as a consequence to refine existing theoretical models.

In particular, cutting-edge research on a macro level refers back to the contributions of *Awerbuch*. Evaluating the generation mix of the European Union (*Awerbuch/ Berger*, 2003), Ireland (*Awerbuch*, 2004) the United States and Mexico (*Awerbuch*, 2006), the cost based study analyses the effect of adding renewable energies to the existing generation portfolios in order to fulfill regulatory targets. In particular wind, geothermal energy and other renewable energies are considered to enlarge the diversity of the generation mix. Following *Awerbuch*, national generation mixes are better off if renewable energies are added.

[5] See Sunderkötter/ Weber (2009), p. 2.

Although renewable energies are costly on a stand-alone basis, including them in a generation portfolio shrinks generation costs and enlarges energy security. The mean-variance approach is not limited to fuel cost analyses, however. According to *Jansen et al.* (2006), *Awerbuch/ Berger* (2003), it is also suitable to explore the incorporation of other sources of risk in terms of operation, maintenance and construction time risks. In addition, another study by *Krey/ Zweifel* (2008) has applied the framework towards different national markets in order to identify efficient generation portfolios, namely those of Switzerland and the United States, and alongside has refined the application by econometric estimations of the underlying covariance matrix. A time varying covariance matrix was first introduced by *Humphreys/ McClain* (1998) to improve the existing analysis framework. Finally, *Bar-Lev/ Katz* (1976) rely on the mean- variance framework to optimize power industries' fuel mixes on a cost-based. Moreover they suggest ratios which allow comparing the performance of regulated utilities in different regions of the United States.

For the German power market, *Sunderkötter/ Weber* (2009) have recently presented an analytical approach by linking elements of mean-variance and of peak load pricing theory. They take two different kinds of gas plants, gas turbine and *combined-cycle gas turbine* (CCGT), as well as lignite, coal, nuclear and existing renewable technologies into account. They find that in contrast to the current German fuel mix, an efficient national generation portfolio should consist of more nuclear and lignite generation capacity based on historically CO_2 prices in comparison to coal generation capacity. However, any restrictions from national energy policy regarding the amount of these generation capacities will change the efficiency of the national energy mix. In that case coal plants turn out to be the most economical technology.[6] The issue arises whether the results and economic implications hold, if their objective function of minimizing costs changes towards the perspective of a utility firm.

In this respect, *Roques et al.* (2008) explore optimal generation portfolios for the power market in the United Kingdom (UK). The analyses focus on base load technologies in order to study the impact of different uncertain variables, namely fuel, electricity and CO_2 prices on generation portfolios. The authors rely on a *discounted cash flow* (DCF) valuation approach and simulate expected *net present values* (NPV). To account for risk a Monte Carlo simulation is used. Within their study they identify the advantages of gas-fired power plants compared to other base load technologies.

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[6] See Sunderkötter/ Weber (2009), p. 26.

As gas and electricity are highly correlated, power plant portfolios that are dominated by gas plants, hedge themselves. Nevertheless, the question arises, whether gas fired plants are able to run base load in the long run. The gas conflict[7] between Ukraine and Russia about transmission services in winter 2008/2009 raises concerns in the EU, whether the reliability of the gas supply is guaranteed.[8]

While *Roques et al.* (2008) conduct the study from an investor's point of view, *Madlener et al.* (2009) choose a company's perspective. The second study conducts portfolio analyses of the E.ON generation capacity operating in the UK and Sweden. Instead of focusing on one certain type of plant technology, they consider the actual generation mixes of these two E.ON subsidies which are evaluated separately. According to their preliminary results the generation portfolios of the E.ON business units are inefficient. The authors advise investing more in renewable energies in both power markets in order to reach an efficient generation mix. The proper investment timing of the new plants remains unanswered, though.

Existing studies (e.g. *Roques et al.* 2008, *Madlener et al.* 2009) assume that the feasibility set and therefore the generation assets remain constant, as power plants are solely valued with respect to their specific economic life-time. In fact, a utility firm which opts for an efficient fuel mix has to take its existing power plants and their respective age structure as well as new investments due to power plant replacements into account. Exploring how a utility firm can realize to operate an efficient power plant park in a target year therefore requires an alternative approach. Otherwise the need for replacements over time would be neglected. In contrast to a static optimization, we define a *dynamic approach* as one which takes the change of a utility's power plant park through time into account. This allows specifying an investment strategy to rebalance a generation portfolio towards efficiency. However, referring to previous research this kind of a multi-period approach has not been taken yet. To fill that gap we develop a dynamic simulation model to conduct a comprehensive portfolio analysis for utilities competing on liberalized markets.

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[7] See Bettzüge/ Lochner (2009), pp. 26-27.
[8] See Krey (2008), pp. 114-115.

1.3 Objectives and methodology

Motivated by the work of *Roques et al.* (2008), we refine their approach from a static to a dynamic analysis. Therefore, the main objective of the thesis is to identify efficient target generation portfolios by taking the perspective of a utility firm which operates on European electricity markets. Hence, we are confronted with picking generation assets which cause operating efficient portfolios not only from an economic but also from a technical point of view. Our challenge is to develop a simulation model which allows rebalancing generation portfolios from a base year towards a target year by conducting the research on a power plant level.

Against this background, we determine the degree of efficiency for generation portfolios. By measuring the degree of - what we call - *relative efficiency* of power plant portfolios, the implications can be used to optimize investment programs. Here, we aim to specify these investment strategies. The tightening emission allocation represents an another interesting issue to our research, as our goal is to measure the impact of value and risk for conventional power plant technologies and therefore generation portfolios. Since major utility firms have started to hold generation assets also in non-domestic electricity markets, we shed light on international diversification effects.

Based on the objectives introduced above, the following research questions have been derived in order to achieve the aims of the thesis:

- Which power plant technologies represent an efficient generation portfolio not only from an economic but also from a technical point of view?
- What does an efficient generation portfolio within a target year look like?
- How can an efficient generation park be realized over time?
- What does a proper investment strategy to optimize expected return and corresponding amount of risk look like?
- How does the change of the emission allocation process affect the profitability of power plant technologies and as a consequence impact the value and risk of generation portfolios?
- Does the operation on international power markets pay off in terms of value and risk?

The contribution of this thesis to the literature is mainly threefold: Firstly, we conduct a comprehensive portfolio analysis from a utility's perspective. Hence, instead of taking single power plants into account (e.g. *Roques et al.*, 2008), we consider a whole power plant park operating with different kinds of fuel technologies. As a consequence, we analyze not only the crucial conventional thermal and non-conventional thermal but also renewable energy power plants. Secondly, we show how to rebalance a generation portfolio in order to operate an efficient power plant park over time. Therefore we develop a dynamic simulation model on a plant basis including the respective age structure and as a consequence a feasibility set which consists of the existing generation capacity on the one hand and new generation capacity on the other hand. To the best of our knowledge, the analysis of a dynamic power plant park that covers existing power plant technologies towards the merit order has hitherto been neglected.

Thirdly, instead of separately valuing European markets on a stand-alone basis, we turn the lens on the exploration of international diversification effects by conducting a cross-national analysis. All in all, we investigate not only the composition of an efficient fuel mix but also *how* efficient European generation portfolios are. Here, we are interested to explore the degree of efficiency of generation portfolios that are actually planned by a utility firm operating on liberalized electricity markets. While utility firms benefit from this approach to measure the performance of generation portfolios and as a consequence be able to optimize their investment program, financial analysts get insights into the degree of efficiency for stock-traded generation business.

Against this background, the thesis relies on the following methodology to respond to the aforementioned research questions: We start in Chapter 2 analyzing the impact of structural changes to the European energy industry. For this purpose, we briefly review the liberalization process and present how investments in generation capacity are affected thereby. As a consequence, we introduce common power plant technologies to detect specific technical and economic merits as these generation assets represent our feasibility set. Irrespective of the kind of technology, power plants operating on competitive markets are already faced with uncertainties, and the introduction of the EU Emission Trading Scheme is a new source of uncertainty. In order to understand these uncertainties which mainly materialize as price risks, we analyze commodity prices, driving forces and mutual dependencies.

Within Chapter 3 in a first step we present the traditional portfolio-valuation theory. Here we briefly review the fundamentals of a discounted free cash flow valuation methodology and show how to combine this traditional valuation concept with a Monte Carlo simulation to account for uncertainties. To solve the risk-return trade-off, we describe the portfolio approach developed by *Markowitz* (1952). However, in comparison to these traditional approaches for financial assets, in a second step we adjust these concepts for generation assets. Therefore we derive, based on the findings of *Roques et al.* (2008), the requirements for our theoretical model. In addition, we derive ratios to determine the degree of efficiency for generation portfolios following capital market theory. The theoretical part of this thesis closes with deriving underlying hypotheses.

Chapter 4 develops a dynamic simulation model for analyzing generation portfolios. Based on the foregone analyses stochastic distributions are presumed for the risky parameters, which have an impact on power generation assets value. In this respect, electricity, fuel and carbon prices as well as meteorological data are defined as exogenous and uncertain variables. Alongside underlying technical and costs assumptions for power plants, we present non-linear commodity price developments for these uncertain variables as well as projected remunerations for renewable energies. Having defined these input variables, we devote the modeling procedure to dynamize a power plant park. Combining the simulation with a DCF approach determines the expected *net present value* (NPV) of a generation asset. While the expected NPV per capacity unit in MW measures the return of a plant, the corresponding standard deviation of the expected NPV serves as measure of risk. The results of the Monte Carlo simulation are used to determine efficient generation portfolios, whereas we distinguish between technical and economic efficiency.

Chapter 5 delivers the empirical simulation results of the analyses. Specifically, we rely on real power plant data provided by *Platts*, commodity prices from European Energy Exchanges and meteorological data from *Deutscher Wetterdienst* (DWD). We test an initial investment strategy leading to a target fuel mix communicated by a European utility firm for efficiency. Our results are presented first on a single power plant basis as well as for portfolios of affiliated technologies. Second, we determine the efficient frontiers before providing results for the country-specific generation portfolios. At last, based on our findings we demonstrate how to rebalance generation portfolios by adjusting the initial investment strategy.

This thesis closes in Chapter 6 with a conclusion, implications not only for management but also for research practice and gives an outlook for further research.