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An analysis of the development of market structures in Central Western Europe (CWE) electricity markets

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Statement of Affirmation

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Abstract

This thesis analyzes the development of market structures on different European electricity markets with focus on the effects of increasing shares of variable renewable energy. Derived research questions address the identification of possible changes in the price structure as well as changes in the traded market volume. In addition, potential trends and shifts between the day-ahead and intraday market segment are examined. For this purpose, market data of various electricity exchanges was collected in form of time series observing the last 10 years. Due to the negligible marginal costs of variable renewable electricity generation, the more expensive conventional power plants are being replaced from the merit order, resulting in overall lower wholesale electricity prices. The strong electricity infeed from photovoltaics during the noon period leads to an adjustment and even partial reversion of the base-peak price structure. Furthermore, decreasing risk premiums on the future market can be identified. Electricity prices on the spot market are significantly influence by wind and photovoltaic infeed forecasts. However, increasing volatility of day-ahead base prices could not be observed, mostly due to the price harmonizing effect of market coupling between the European electricity markets. In the observed period of 10 years, spot market volumes have remarkably risen, with the most significant increase on the intraday markets. Also apparent is the direct relationship between increasing intraday volumes and rising wind and photovoltaic capacities, due to need of compensating short-term prediction errors. Rising volumes can also be seen on the future markets, mostly attributable to market-specific characteristics. However the share of market segments and their development differ significantly between European market regions.

Kurzfassung

Ziel dieser Arbeit ist es die Entwicklung von Marktstrukturen auf verschiedenen europäischen Strommärkten zu analysieren und die Auswirkungen des steigenden Anteils aus variabler erneuerbarer Energie zu untersuchen. Auszuarbeitende Forschungsfragen dabei sind das Feststellen von eventuellen Änderungen der Preisstruktur als auch Veränderungen am gehandelten Marktvolumen. Weiters sollen möglichen Trends und Verschiebungen zwischen dem Day-Ahead und Intraday Marktsegmenten untersucht werden. Hierzu wurden Marktdaten diverser Strombörsen in Form von Zeitreihen über die letzten 10 Jahre gesammelt und in einheitlicher Form aufgearbeitet. Aufgrund der kaum vorhandenen Grenzkosten von fluktuierender erneuerbarer Stromerzeugung werden teurere konventionelle Kraftwerke von der Merit Order verdrängt was zu generell niedrigeren Großhandels-Strompreisen führt. Die in der Mittagszeit starke Einspeisung aus Photovoltaik führt zusätzlich zu einer Angleichung und teilweise sogar Umkehrung der Base-Peak Preisstruktur. Weiters kann die Verringerung von Risiko Prämien am Future Markt festgestellt werden. Die Strompreise am Spotmarkt zeigen eine deutliche Beeinflussung durch Wind und Photovoltaik Forecasts. Eine steigende Volatilität der Day-Ahead Base Preise kann jedoch nicht beobachtet werden, was unter anderem auf die ausgleichende Wirkung der zunehmende Kopplung verschiedener Marktgebiete zurückzuführen ist. Im beobachteten Zeitraum von 10 Jahren sind die Handelsvolumen an Spotmärkten deutlich gestiegen wobei die signifikanteste Steigerung am Intraday-Markt festgestellt werden kann. Ebenso ist ein direkter Zusammenhang von steigender Wind und Photovoltaik Erzeugung und steigendem Intraday-Volumen ersichtlich, was auf die Notwendigkeit zurück zu führen ist, kurzfristige Vorhersagefehler vor der tatsächlichen Erzeugung noch auszugleichen. Steigende Volumen können auch am Future Markt festgestellt werden, wobei dies jedoch hauptsächlich auf marktspezifische Eigenheiten zurückzuführen ist. Generell unterscheiden sich der Anteil der Marktsegmente sowie deren Entwicklung deutlich zwischen den europäischen Marktgebieten.

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1 Introduction

1.1 Motivation

The liberalization of the electricity market enabled the introduction of European power exchanges in the 1990s. The monopoly structures of electricity supply should be dissolved and replaced by market mechanisms for electricity trading and the operation of power plants. Competition in electricity markets should contribute to achieve optimal prices. In particular, this European-wide liberalization of the electricity markets was intended to significantly reduce the price of electricity through the market mechanisms, not just for the industry, but for all electricity customers. To ensure competition in the long run, different market segments exist like short-term spot markets and long term future markets. Trading takes place on exchanges as well as by bilateral settlements, the so-called over the counter trading. In recent years a major change towards renewable energy has started.

Primary initiators for the abrupt hike in European energy production in the recent past were largely political decisions to improve climate protection. Preceded by the globally negotiated Kyoto Protocol which set internationally binding emission reduction targets, the Paris Agreement followed, aiming to keep a global temperature rise this century below 2 degrees Celsius above pre-industrial levels. On European side the 2020 Climate & Energy Package was adopted to ensure the EU meets its climate and energy targets for the year 2020. The package sets three key targets which are a 20 percent cut in greenhouse gas emissions from 1990 levels, 20 percent of EU energy from renewables and a 20 percent improvement in energy efficiency. In 2014 the 2030 Climate & Energy Framework was adopted by EU leaders which tightens the three key targets to a 40-27-27 percent level for the year 2030. Furthermore Germany aims for eliminating nuclear power production within 2022 and so requires large increases of new energy capacity.

For these reasons, a remarkable rise in variable renewable energy from wind and photovoltaics has been recorded in Europe in the past years. Wind power and solar power plants does not cause any CO2 emissions but differ significantly from conventional power generation regarding their operating behavior. Due to the dependence of wind and solar radiation, output is not directly controllable and furthermore subject to large fluctuations. This of course also has influence on the energy market and impacts price and volume structures in different market segments. Goal of this thesis is to find out the magnitude of this impact on different European electricity markets which results from the rising share of variable energy.

1.2 Objective

The objective of this work is to analyze the development of market structures in CWE electricity markets over the past ten years. This includes investigation regarding price structures, traded volumes, as well as to investigate how the shares of market elements like future, day-ahead and intraday markets changed over time. Investigations are conducted on the main European electricity markets which cover the Nordic, German, French, Italian, and Czech market area as well as the Iberian Peninsula. In particular, the following three core objectives are dealt with.

- First topic of interest is if and how the traded volumes on European electricity wholesale markets changed over time. To be analyzed are developments on intraday, day-ahead as well as future exchanges. Furthermore, traded volumes of the various electricity exchanges have to be summarized by certain market regions because some areas are covered by several exchanges which operate in direct competition to each other. Primary of interest are volume developments of each market segment in the specific regions.
- Second research question of this work is to find out if there are possible trends regarding changes in the shares of market segments. Since volumes on future exchanges are traded several times before the actual delivery and therefore are also taken into account several times, no direct comparison to the intraday and day-ahead exchanges can be drawn. In contrast, volumes traded on the spot-market are only recorded once and therefore represent the exact amount which is physically delivered. Therefore the development of the spot-market composition is being analyzed in different European market regions to evaluate if there are any observable trends between the shares of intraday and day-ahead segments.
- The third research question to be elaborated concerns the development of price structures within the last ten years. This includes analyzing the overall price development on day-ahead markets, as well as investigations on risk premiums for various European future exchanges. Furthermore the development of spot-price volatility and changes between base and peak prices on several market regions are of interest.

The effects of variable renewable energy generation on the electricity wholesale market is exemplified in theory using a fundamental market model, based on an inelastic demand curve and a marginal cost dependent supply curve also called merit order. For investigations on market development regarding traded volumes and price structures, historical market data is being analyzed. Therefore market data in form of time series is being collected, processed to a comprehensive, uniform database and subsequently findings are prepared and illustrated in various diagrams.

1.3 Structure

Starting with a conducted literature study, a brief overview of current research topics is provided as well as a summary of existing literature regarding renewable energy and its influence on the electricity wholesale market. Chapter 3 contains the theoretical foundation concerning electricity trading and variable renewables. This includes in a first sub-section information about wholesale market structures which are followed by market fundamentals like market modeling and electricity pricing and concludes with information about wind and photovoltaic generation capacities and peculiarities. Furthermore, chapter 4 deals with the data collection of all used market data in this work and provides an overview of the final database. Market data then is presented and analyzed in chapter 5 where time series are illustrated in several diagrams concerning the different research questions including a description of the resulting findings. The chapter starts with an overview of the current market composition in 2016. Further sub-sections deal with price and volume developments on day-ahead, future and intraday markets in Europe followed by the therefore resulting market structure shifts and a detailed analysis of the German spot-market and the observable impacts of variable renewables. Chapter 6 finally summarizes this work and the main findings.

2 Literature Study

This chapter should give a brief overview of current related research topics and summarizes existing literature regarding renewable energy generation and its influence on the electricity markets. Topics related to the electricity production from renewable energy has been widely discussed in recent studies as a result of a rapid transition from conventional electricity generation due to political and environmental motivated decisions. However, at the time of writing hardly any literary work is known, that like this thesis deals specifically with effects on market structures resulting from increasing shares of variable renewable energy. Furthermore, the broad observation period of ten years and a simultaneous consideration of a large part of the European electricity exchanges is a key feature of this thesis.

Recent research mainly focused on how variable renewable energy such as wind and photovoltaics could be integrated in the electricity market. One of the most discussed topics deals with the ongoing decrease of electricity wholesale prices due to rising shares of renewables. Also a highly discussed topic concerns the high volatility of weather dependent electricity output by wind and photovoltaic and the resulting problem of network compatibility. Another topic deals with system stability and security of supply due to the necessity of conventional power plants which can act as additional backup in periods of low availability from renewable generation, but however slowly get pushed off the market due to the low electricity prices. As mentioned before, literature addressing the development of trading volumes as well as shifts in market structures is very scarce.

Literature concerning the electricity wholesale prices concludes uniformly that there is a price decreasing merit order effect of renewable energy due to their negligible marginal generation cost. Investigations of the German market prices has been done by Pham and Lemoine [1] applying a GARCH framework on the electricity spot price in the period 2009 to 2012 and Würzburg et al. [2] applying a multivariate regression approach. Similar results are found by Gelabert et al. [3] for the Spanish day-ahead market and Clo et al. [4] applying a multivariate linear regression model on the Italian spot market. Kamperud and Sator [5] analyze and compare the fundamental drivers behind electricity spot prices in Nord Pool and the German EPEX using a linear quantile regression. Ortner et al. [6] investigated several European countries which cover 73 percent of the renewable energy source share in Europe’s regional electricity markets using a multivariate regression analysis. They conclude that all considered countries show a consistent negative impact on spot market prices and a decreasing market value of renewable energy sources with rising shares.

In addition to the merit order effect, further studies also address rising spot price volatility due to the increasing share of variable renewable energy generation. Using a static market model and data from Germany, Wozabal et al. [7] show that small to moderate quantities of variable energy production tend to decrease the price variance while large quantities have the opposite effect. Nicolosi and Fürsch [8] study the consequences for the conventional generation capacity mix in Germany, considering the growing share of renewable energy. They find that more variable energy increases the volatility of the residual demand which in turn increases the volatility of the electricity price. Ketterer [9] also examines the impact of wind on the German electricity prices using a GARCH model and concludes that the price level is reduced due to the wind power generation, while the volatility increases. Paraschiv et al. [10] studied the German day-ahead prices using a state space model and find that renewable energy increases the extreme price fluctuations, and that the price sensitivity differs for each variable in each trading period.

According to Gullberg et al. [11] and Jacobsen & Zvingilaite [12] looking at the resulting variability issues arising by the increasing number of renewable energy plants, security of supply is ensured by having sufficient flexible reserves. This can be achieved by installing more peak load plant capacity, enhance energy storage or improve interconnections between areas. LI [13] states that strong interconnections cause more stable prices and an increasingly competition that further limits opportunities to exercise market power during periods of low supply. The effect on spot prices of overcapacity in order of the volatility of wind and photovoltaic has been discussed among others by Cartea & Villaplana [14].

A very comprehensive study on the influence of renewable energy on the electricity market is given by Hildmann [15]. He analyses the integration of renewable energy sources into the liberalized markets on a short/mid-term horizon as well as on long–term perspective and concludes that the transition towards higher renewable shares is possible without the introduction of capacity markets. He proposes an increase of the relative volume of the day-ahead market to limit the merit order effect in the short- and mid-term horizon and states that in the long run, the price structure will adapt to the new situation of the renewables with the phase-out of RES support schemes, in which they face a competitive market situation.

Based on the research question concerning the development of market volumes and structures a study of Kleb [16] has to be highlighted. The study addresses questions concerning how the increasing share and importance of renewable energy plants and the thereby corresponding level of overcapacity influences the wholesale market prices as well as the trading volume ratio in electricity markets. Statements about clearing prices, the risk premium and decision behavior are given by simulation of different share of renewable energy and level of overcapacity. In a first experiment is shown that with replacing conventional power plants by renewable power the forward market clearing price is decreased caused by the lower marginal costs. At the same time however, a higher share of renewable capacity increases the overall output volatility, which leads to a higher demand in the spot market, where renewable plants have to balance their cleared capacity and actual output. Therefore the spot market clearing price increases when renewable capacity replaces conventional capacity. Following, this decreases the risk premium which is defined as forward market clearing price minus spot market clearing price.

In a second experiment the absolute amount of conventional energy stays constant while the share of renewable capacity as well as the level of overcapacity increases. This scenario is more realistic since conventional power plants will not immediately be closed when more renewables energy is added to the market. Findings show that the risk premium also in this setting decreases if additional renewable capacity is added to the market due to lower marginal costs as well as market overcapacity. However, while the forward market clearing price decreases, the spot market clearing price is not significantly moving into one direction. This can be attributed to the opposing effects of increasing renewable capacity and rising overcapacity at the same time, which approximately offset each other. The higher share of renewable energy increases the spot market clearing price due to a growth of the spot market demand by the increased output volatility, whereas the higher overcapacity leads to growing competition and thereby decreasing the spot market clearing prices.

Furthermore Kleb [16] states that the decrease of the risk premium influence the bidding behavior of the market participants and changes the relative attractiveness between the spot and forward market. Significant results indicate that both, renewable as well as conventional plants decrease their bid capacity in the forward market in order to be able to gain more profit by clearing capacity for a higher price in the spot market.

Concluding the literature survey it can be said that the influence of renewable energy production on electricity prices has been very broadly discussed while on the contrary studies analyzing the traded volumes on spot or future markets and associated shifts in the market structures are very scarce. Studies analyzing trading behavior on the OTC markets as well as studies concerning market figures like churn rates have not been known at the point of writing this thesis. This is probably due to the lack of available market data on OTC markets.

3 Theoretical Background

This chapter provides a comprehensive theoretical background concerning electricity trading and its peculiarities. This includes information about the function and framework conditions of the different market segments like future, day-ahead and intraday markets as well as the parallel carried out over-the-counter trading. Furthermore market fundamentals as well as information about price formation is provided with regards of demand factors and the merit order curve representing the supply side. The final sub-section of this chapter concludes with comprehensive information about installed capacities of variable renewables and resulting effects on the electricity market due to their weather dependent output characteristics.

3.1 Wholesale market structure

The electricity wholesale market can be divided in different segments which are distinguished by the time period between settlement and the actual delivery of electricity. Therefore the wholesale market is divided into the future market, day-ahead market and intraday market as seen in Figure 3.1. On the future market electricity is traded far before the actual delivery. This market is primary used to hedge price risks by settling trades more than up to 5 years before delivery. The day-ahead market is the price determining market which brings together supply and forecasted demand one day before the actual delivery. Subsequently trading on the intraday market begins which is possible up to 30 minutes before delivery. The intraday market is used to adjust load profiles and react to forecast errors and other unplanned events. [17]

Figure 3.1: Delivery periods of market segments

Furthermore electricity trading can be separated in exchange trading and co existing over-the-counter trading, which meet complimentary trading conditions. The basic market composition is illustrated in Figure 3.2. Electricity wholesale markets in Europe show high similarities regarding their structure and differ mostly in exchange-specific trading rules and details. Power markets can be sub-national, national or multi-national markets, depending on local needs and county size. Beside the wholesale market there is also a market for ancillary services which covers several market-traded or advertised services from transmission system operators regarding frequency control, voltage control, power loss compensation and reactive power compensation. In contrast to the as energy-only market acting wholesale market, which means that only actually delivered power paid, the market setup of ancillary services also rewards the provision of capacity additionally to the actually delivered power [15].

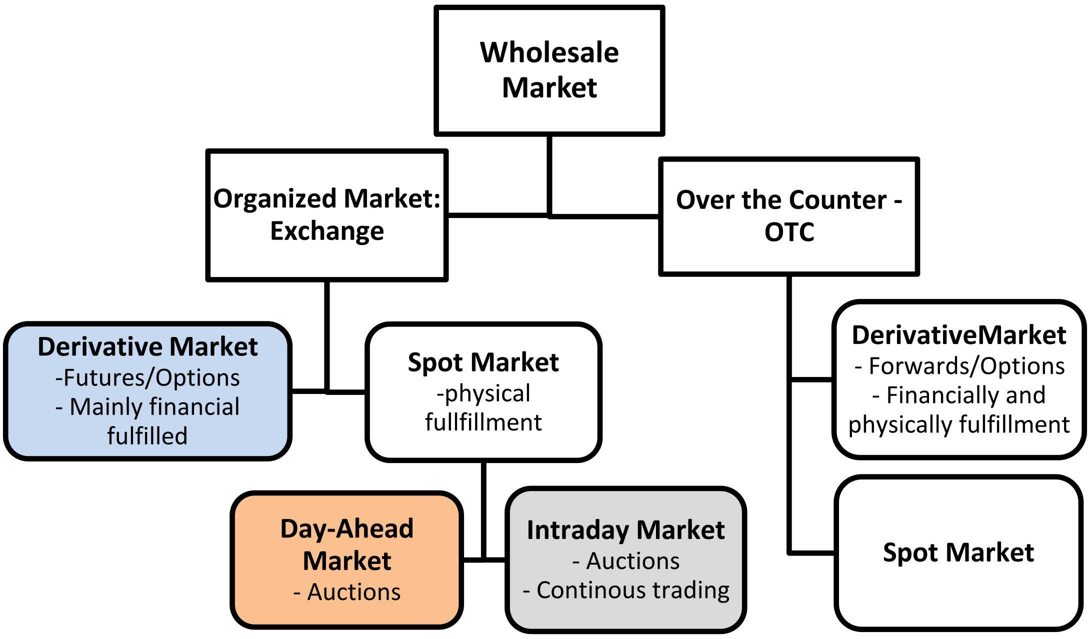

Figure 3.2: Wholesale Market Structure

3.1.1 Future Market

Future trading is determined by settling trades with an actual delivery taking place somewhere in the future. Electricity future markets resemble other commodity markets such as those of oil, natural gas and emission allowances [15]. Transactions are carried out over a long period of up to ten years or more in advance, however the market liquidity decreases with a further fulfillment period.

Future markets are used to reduce risk, mitigate market power, and coordinate new investment. Settling future contracts let suppliers and demanders lock in energy prices and quantities for the time period in the future and therefore reduce risk for both sides of the market by reducing the quantity of energy that is traded at the more volatile spot market [18]. In addition to the traders who are interested in their physical position as producers, suppliers and large consumers, there are also speculative participants like banks. If more power is offered to the market than demanded by distributors at an early stage, speculative participants buy this energy and keep it as a speculative position until market demand is met, hoping to sell at a higher price. Prices at the future markets reflect the expected average price over the respective time period in the future added by a risk premium for the compensation of bearing the spot price risk [19].

Highly standardized products such as futures, options are traded on exchanges, which are supplemented by individual over-the counter traded forward contracts and options. Contracts can be exercised by physical delivery as well as by financial fulfillment, varying from one market to another, with financial fulfillment being more common. Traded contracts on the future market are organized in weekly, monthly, quarterly and year contracts which are further divided in base and peak. Base contracts denote a constant delivery of power over 24 hours a day during the contract`s delivery period. In the case of a peak contract, the seller delivers the nominal output only from Monday to Friday from 8 am to 8 pm, which represents the time period with high demand.

Along time, market participants gain new information and may need to adjust their future contracts accordingly. For example, a retail company gains more accurate forecasts regarding the electricity demand of private households and needs to update positions taken in the futures market [20]. As the point of delivery coming closer, power exchanges operate spot markets where electricity is traded one day before the actual delivery to balance actual supply and demand.

3.1.2 Day-Ahead Market

Day-ahead markets can be considered as the reference markets in most power systems and result in an allocation which is closer to the point of delivery. They allow the sale or purchase of electricity for the following day using mainly hourly blocks, as well as complementary base, peak and further products varying between the different power exchanges. The day-ahead markets are used to optimize daily plant generation profiles as well as to adjust the portfolio of purchases and sales for the following day. Electricity traders fulfill their obligation to balance their own balancing group on the basis of current load forecasts and the currently planned power plant use.

Day-ahead markets in Europe are generally organized by an auction based market structure. Submitting bids for electricity with delivery on the following day is usually possible until 12:00am. The trading system then feeds the information into a computer system which calculates the price also taking available cross border capacities into account. The price is set where the curves for sell price and buy price meet for each hour. The determined equilibrium price and volume increases price transparency and furthermore decreases direct liquidity costs. Once the market prices have been calculated, trades are settled, however times vary slightly between different exchanges. Hourly prices are typically announced to the market an hour after gate closure [21].

Market Coupling

In the past decade various electricity market areas and spot exchanges got coupled to optimize the allocation of cross-border capacities using a coordinated calculation of prices and flows between regions. This allows minimizing the price difference between two or more markets and consequently increases price convergence. By doing so, market coupling maximizes the social welfare and provides information for the investment in cross-border transmission capacities. Cross-border trading furthermore harmonizes price peaks and therefore contributes to integrate the rising shares of variable electricity generation.

Starting in 2006 the French, Belgium and Dutch day-ahead markets were coupled in the Tri-Lateral Market Coupling (TLC). In 2010, Central West Europe (CWE) was launched, coupling Benelux, France and Germany with parallel coupling to the Nordic region via the Interim Tight Volume Coupling (ITVC). In the same year South Western Europe (SWE) market region was created by linking Spain and Portugal. Another important step regarding European market integration took place in 2014, when Price Coupling in North Western Europe (NWE) was started, first using the pan-European PCR solution for the calculation of prices and flows. In the first half of 2014 the NWE market covered the region of CWE, Great Britain, the Nordics and Baltics. At the end of 2014 the SWE and NWE markets coupled, called Multi-Regional Coupling (MRC). Italy also connected to the MRC area in 2015. Consequently the now coupled area covers 19 countries which represent about 85 percent of European power consumption. [22]

3.1.3 Intraday Market

Intraday trading takes place after day-ahead gate closure and therefore represents the market closest to the actual delivery. Especially in a power system with a high share of variable renewable energy, significant deviations can arise between the day-ahead forecasts and the actual feed-in [20]. Forecasting of VRE generation becomes increasingly accurate the closer it gets to delivery. Therefore the intraday market provides the possibility to react to such information by allowing market participants to adjust their electricity portfolios close to physical delivery. For example on the EPEX Spot intraday market, trading is possible until 30 minutes before the actual start of delivery [23]. This on the one hand benefits the entities who have unbalanced positions and on the other hand gives additional profit opportunities to those market participants who can offer to compensate for these imbalances.

While all European day-ahead markets generally operate using an auction based market structure, on intraday markets two different exchange-based trading designs are used: the auction-based market design like on day-ahead market as well as the continuous trading design. Continuous intraday markets like Nordpool or EPEX Spot consist of a limit order book that stores incoming buy and sell orders while trades are immediately executed as soon as the bid price meets or exceeds the ask price. Continuous markets allow 24/7 trading and thus offer immediacy so that market participants may trade imbalances as soon as they appear.

In auction-based intraday markets like in Spain or Italy, market participants bid in several intraday auctions. Aggregated demand and supply curves then are matched for every delivery period. In 2013 EPEX Spot Exchange introduced 15 minute blocks on their intraday market. This allows market participants to trade in smaller time units and thus help to manage fluctuations as well to model the steep production ramps of photovoltaic generation. Small deviations will nevertheless arise until physical delivery. These mismatches between supply and demand generally require instant response, and are therefore not manageable by exchange trading. The so called ancillary services generally are managed by transmission system operators. [24]

3.1.4 OTC Market

Complementary to the electricity exchanges, trading also takes place via the so-called over the counter market. The OTC market played a leading role after the liberalization of electricity markets, since only standard products were offered on energy exchanges [25]. In the case of OTC trading, individually negotiated contracts are concluded between two parties, resulting in a high degree of flexibility. Contracts covering an individually agreed period are settled, ranging from hours to several years in advance. OTC transactions are primarily focused on the actual physical fulfillment of transactions [26]. Exchanges, on the other hand are organized marketplaces where supply and demand are regularly brought together using highly standardized products. These products serve as a common denominator and satisfy the needs of traders, hedgers, arbitrageurs and speculators alike, primarily exercised by financial fulfillment. Therefore in order to fully meet the individual needs of all market participants, exchange trading needs to be supplemented by the OTC market [27].

Since the negotiation of individual contracts can be time intensive, transaction costs of over-the-counter trades are higher than on the highly standardized exchanges [28]. Respective contract partners are usually known, which furthermore results in lower anonymity. In the case of a counterparty default, over the counter contracts are not executed, whereas electricity exchanges guarantee the physical and financial fulfillment of transactions by taking over the credit risk [27]. Exchanges generally offer higher liquidity resulting from a larger number of market participants and the therefore resulting larger supply and demand volumes, which makes settling contracts possible at any time. In addition, exchange trading is characterized by higher market transparency by providing all market participants the permanent opportunity to gain an insight into market events. Nevertheless, over-the-counter trading is predominant in many market areas and despite the advantages of power exchanges, still shows higher volumes in most cases [29]. [17]

3.2 Electricity Market Fundamentals

3.2.1 Market Modeling

Electricity by its nature cannot be economically stored and has to be produced at the same moment it is delivered to the final consumer. This means, supply and demand must be in balance at any time. [30] Therefore, it is not possible to keep it in stock or ration it like other commodities. In addition, demand and supply vary continuously which altogether leads to significantly different market behavior compared to common markets.

Electricity prices on the day-ahead markets are most important and can be considered as the reference price for electricity. The various factors which influence the price formation are described using market models which can be distinguished in fundamental or statistical models. Statistical models do not model the underlying market mechanics and work directly on price or load time series, characterizing the time series as a stochastic process. The majority of the models are auto-regressive with external inputs and are trained on past data [31]. These models can estimate volatility but their main downside is the slow reaction to market structure breaks and the lack of incorporating underlying physical information.

On contrary to financial markets where the underlying mechanics are mostly unknown, electricity markets are based on physical principles and consequently the modeling of demand and supply curves is possible. The wholesale market consists on the supply side mainly of electricity generators and importers, and on the demand side large consumers and retailers who buy power to sell-on to smaller consumers [32]. Fundamental market models describe those market structures and are able to determine the electricity price by bringing together supply and demand factors, and therefore are useful in many aspects of electricity modeling [33]. Their main downsides are the complexity of the model due to the large amount of information required and the incapability of volatility estimation. [15]

3.2.2 Merit Order

Summarized, the merit order can be described as a ranking of available electricity generation sources in ascending order based on their marginal costs. The so called merit-order-curve therefore represents the electricity supply side and shows the available amount of energy sources ranked from lowest marginal cost to the highest [34]. It is modeled as a marginal cost curve mainly dependent on fuel costs, the efficiency of the power plants and emission prices. With rising electricity demand, the more expansive plants are operating. Figure 3.3 shows the theoretical structure of a merit order curve and the price formation where the rather inelastic demand curve intersects with the merit order curve.

On the left side of the merit order curve are renewable power plants with nearly zero marginal costs like photovoltaic, wind and hydropower. These plants have the highest priority to be used in an economic and environmental view. Going further to the right, the curve consists of so called baseload plants like coal fired and nuclear plants with comparable low marginal costs. Base load power plants are characterized by a slow demand respond and therefore usually provide a continuous supply of electricity throughout the year only be turned off during periodic maintenance and service. On the right side of the merit order curve are load following and peak power plants. Gas and oil power plants show relatively high marginal costs but can be started and turned off compareable easy to follow demand. In times whith high demand an low supply from renewable energy, peak load is provided by pumped-storage hydroelectricity.

Power stations which are on the left side of the demand curve are therefore used to generate the actual electricity demand, while plants to the right of the intersection stand still. All generating power plants are remunerated by the hourly determined day-ahead market price, irrespective of their actual bid at the exchange.

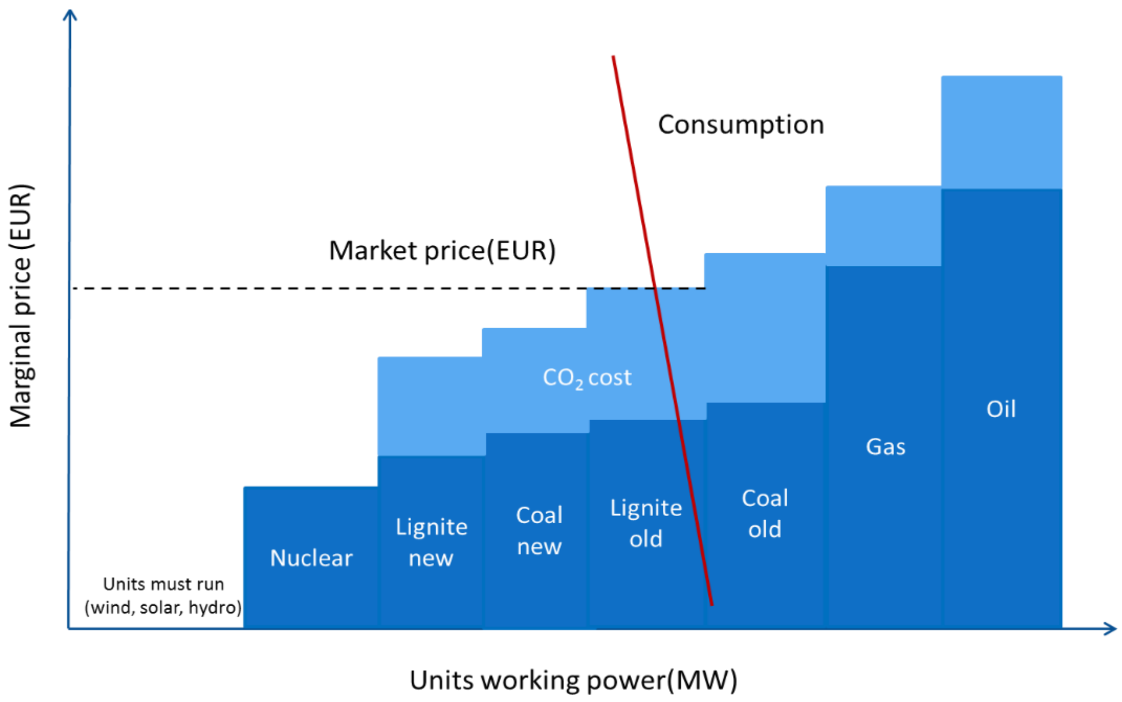

Figure 3.3: Merit Order Curve - Electricity pricing with supply and demand [72]

3.2.3 Electricity Pricing

The reference prices for trading electricity is determined in daily spot market auctions for each hour of the day. Market participants are able to place bids containing price and volume information of their planned sales and purchases. After gate closure an equilibrium price is determined where supply meets demand at which all settled trades are remunerated, regardless of the actual bid price from each participant. Prices however differ between market regions and exchanges depending on varying supply and demand situations as well as available cross border capacities.

The supply situation can be expressed by the merit order curve. Due to the short time between auctions and actual delivery, the bid price from suppliers depends only on their variable costs which in turn consist for the most part of fuel and emission costs. The demand curve is modeled based on seasonal and environmental factors and shows low price elasticity on the short-term. Electricity spot prices therefore show unique patters which are to a large extent caused by the seasonality of underlying supply and demand factors as well as the non-storability of electricity in an economic way. As a side effect of the missing availability of economic storage, trading electricity is furthermore determined by higher price volatility compared to other commodities [35]. Most characterizing patterns regarding electricity spot prices are the mean reversion, seasonality, significant peaks and a high and clustered volatility.

Spot price mean reversion is resulting by the underlying fundamental price building principle of supply and demand. A sustainable long term change in the price level therefore can only occur due to market structure changes or governmental interventions, which furthermore implies that the short and medium term prices tend to revert towards the mean. Seasonal patterns are mainly caused by fluctuating electricity demand. Main demand driver is consumer behavior which is strongly influenced by day/night cycles and week-day/weekend patterns and summer/winter seasonality. Especially the outside temperature needs to be emphasized since heating is a major electricity consumer [15].

Unusual supply and demand situations which are rare but mostly caused by uncommon weather conditions can furthermore lead to electricity price peaks. Very high electricity consumption can for example be the result of extraordinary cold temperatures and therefore higher heating demand, while unusually low hydro power availability is possible to occur at the same time due to the freezing temperatures. Positive spikes mainly occur when high demand meets low supply, for example during weekdays at daytime with temporary very low production from renewable energy at the same time. Negative spices are therefore caused by the inverse supply/demand situation. In some cases even electricity prices below zero are possible in periods of high renewable infeed and low demand [10]. During bottleneck periods the possibility of price extremes increases and therefore peaks are followed by similar peaks, indicating volatility clustering [36]. [37]

Figure 3.4 shows the interrelation between demand, supply and the resulting day-ahead price in the case of five random days starting from Wednesday to Sunday in Germany in 2015. The total load profile states the consumed electricity and therefore represents demand. As observable, the demanded electricity varies between night and day as well shows significant lower amounts on weekends. The residual load is calculated by subtracting the forecasted renewable power infeed from the total demand and therefore represents the amount of power which has to be produced by conventional power plants. To preserve simplicity, cross border flows were not taken in account when creating this diagram. Residual load significantly decreases with higher renewable infeed, most drastic at noon caused by high photovoltaic generation. Furthermore it can be observed that determined spot price shows strong correlation to the residual load. The price decreasing impact by rising electricity generation from renewable energy is called merit-order-effect and is discussed more precisely in chapter 3.3.3.

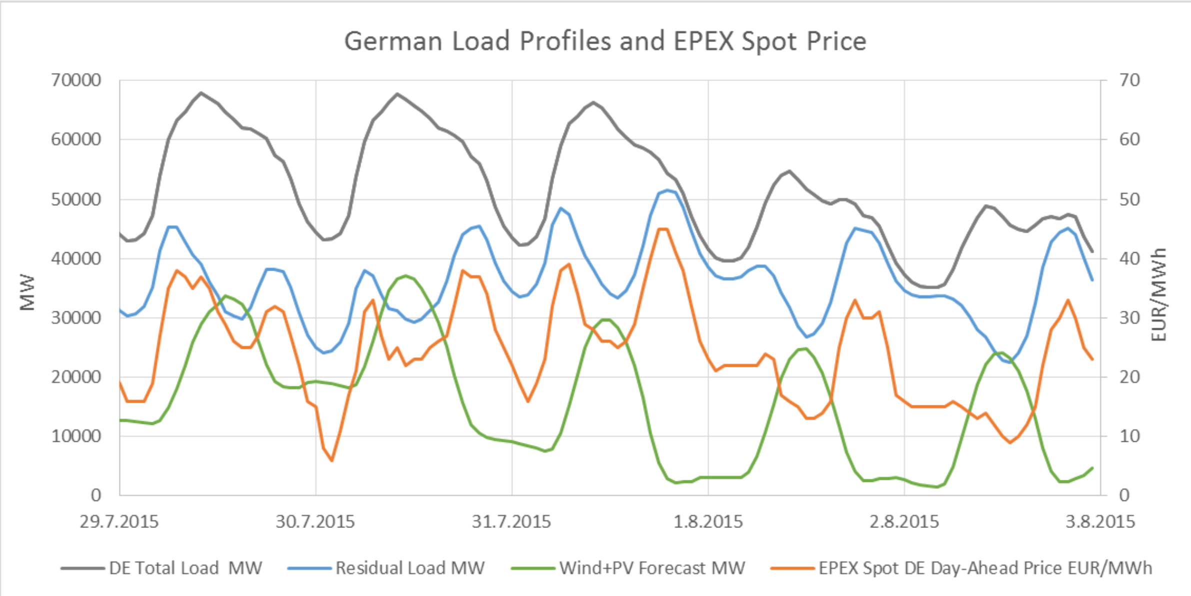

Figure 3.4: German Load Profiles and EPEX Day-Ahead Price

3.3 Variable Renewable Energy

Renewable energy sources in general are defined as energy carriers which are virtually inexhaustible or relatively rapidly renewed. A shift away from conventional power generation towards renewable and therefore CO2 neutral sources such as hydro, wind, photovoltaic and biomass is inevitable to comply with the set climate criteria. The eligible technologies differ in terms of predictability and availability due to their underlying physical fundamentals. The generation of hydro and biomass power plants is well controllable and calculable and therefore also suitable for covering basic load. However, the potential for new hydropower expansion is almost exhausted from an economic and environmental point of view, preventing any further increase of its share. Biomass also deals with the problem of too much required space for the growth of new raw materials which prevents further investments.

Therefore a steady increase of renewable energy from wind and photovoltaic systems is currently taking place. Due to difficult predictability caused by their characteristic weather dependent performance fluctuations they are also referred to as variable or intermittent renewable energy sources. Solar generation is additionally determined by steep production ramps and generation only during daytime. Due to support scheme regulations and its weather dependent unpredictability on a long term horizon, variable renewable energy is mainly traded on the day-ahead market. Since the actual energy output is only known at the time of delivery, trading on the day-ahead market is based on forecasted volumes. The link between renewable electricity generation and spot market volumes is analyzed more in detail based on German market data in chapter 5.7.

3.3.1 Installed Capacities in Europe

Looking at the annual installed wind power capacity in the observed European countries over the past ten years a constant rising trend can be found as shown in Figure 3.5. Between 2006 and 2014 this trend was mainly contributed to Germany and Spain. Also significant increases can be seen in Italy and France. In 2013, Italy and Spain nearly stopped investments in new plants due to an electricity market reform and a reduction of financial support, while Germany more than doubled the amount of yearly installed wind production power. France shows relatively constant growth rate over the whole decade. Figure 3.6 presents the cumulative installed wind power capacity. Leading countries regarding wind power production therefore are Germany and Spain. In the year 2016 wind power in Germany has contributed about 11.9 percent [38] and in Spain about 17.8 percent [39] of the total electricity produced. The total installed wind power capacity of the EU-28 countries at the end of 2016 amounted to 153 GW [40].

The annual installed solar power capacity of the observed countries in this thesis is presented in Figure 3.7. Yearly investments were strongly increasing until 2011 due to generous financial incentives like feed-in tariffs where the generated electricity could be remunerated regardless of the actual traded spot price. Main drivers were Germany and Italy. Since 2012, electricity reforms and adjustments in renewable support schemes then slowed down annual investments in new solar power plants. As shown in Figure 3.8, Germany and Italy therefore are Europe’s leading countries regarding the cumulative installed solar power capacity. In Italy photovoltaic power covered 7.2 percent [41] of the electricity demand in 2016, while in Germany about 5.9 percent [38] of total demand was contributed by solar power. The total installed photovoltaic capacity of the EU-28 countries at the end of 2016 amounted to 100 GW [42].

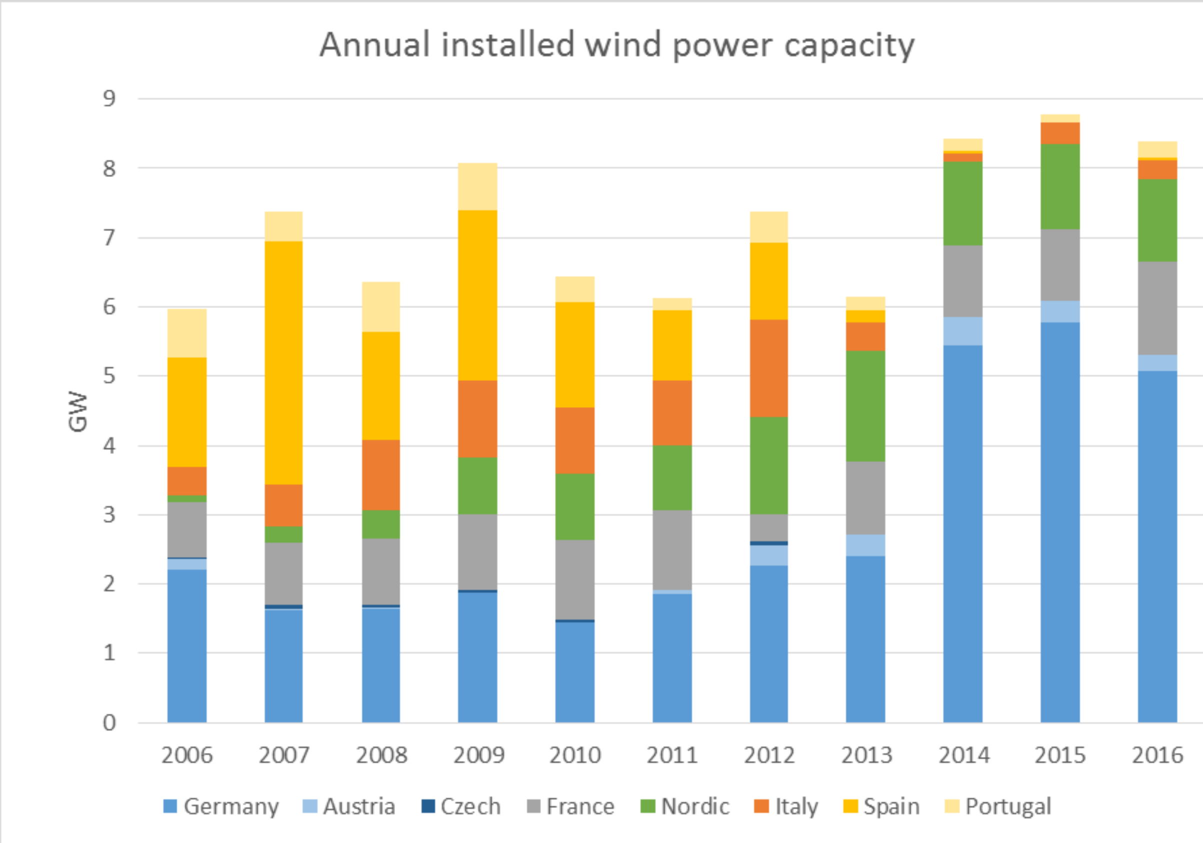

Figure 3.5: Annual installed wind power capacity

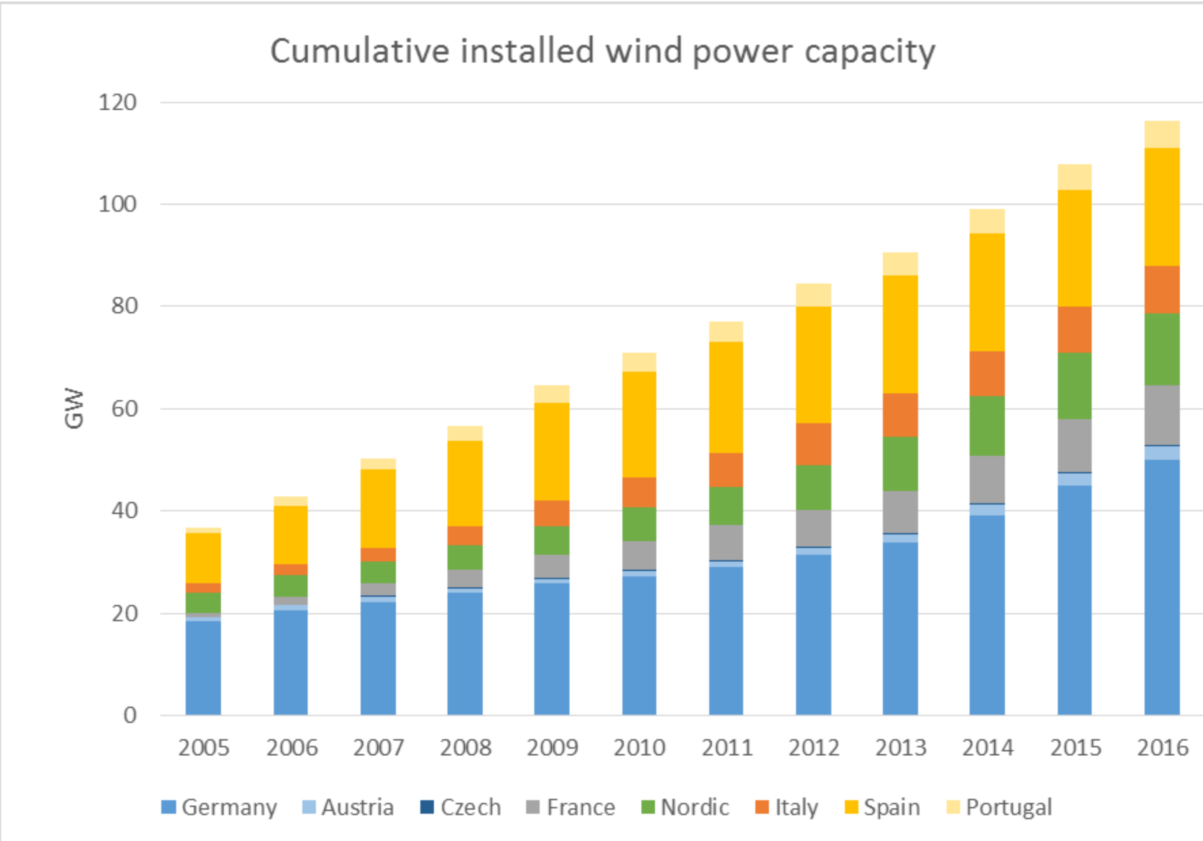

Figure 3.6: Cumulative installed wind power capacity

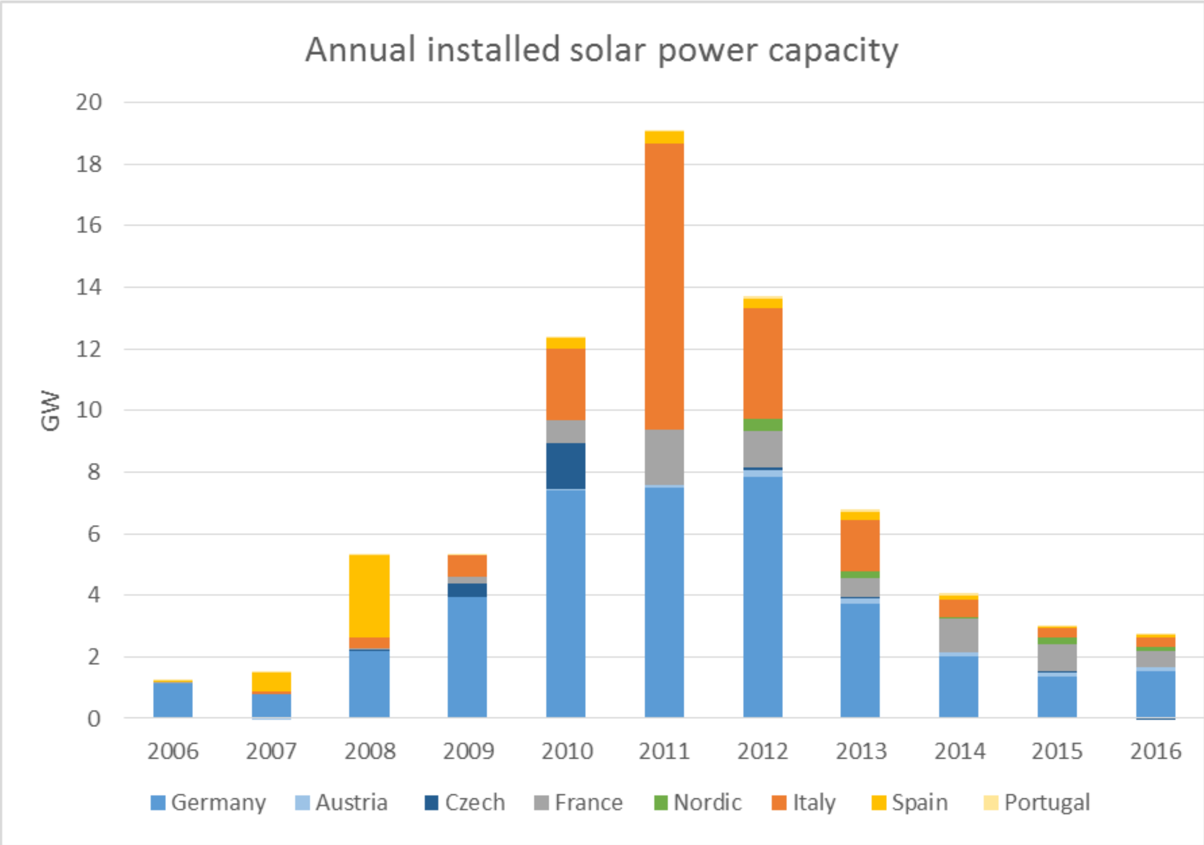

Figure 3.7: Annual installed solar power capacity

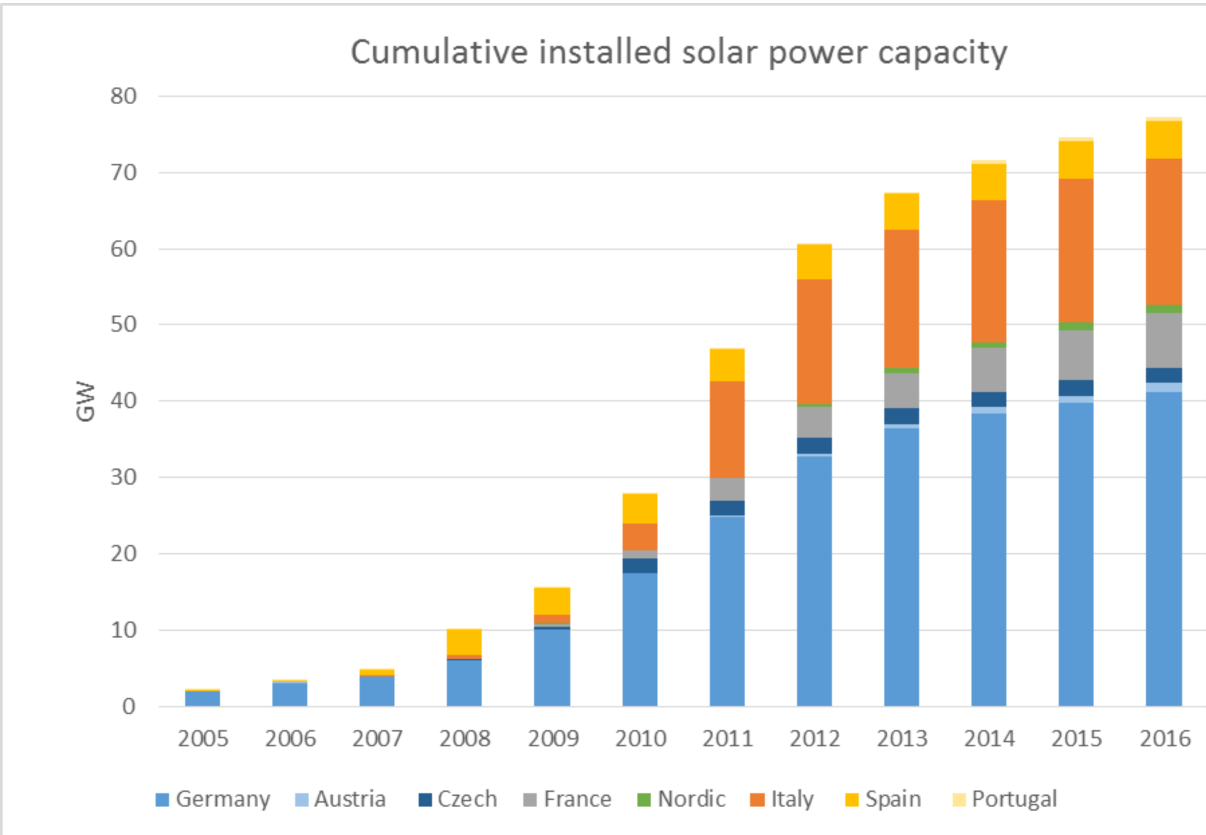

Figure 3.8: Cumulative installed solar power capacity

3.3.2 Variability and Forecast Errors

The strong fluctuating output profiles of variable energy sources is shown in Figure 3.9, where one random week in summer 2015 in Germany was selectet to illustrate the characteristics of electricity generation from wind end photovoltaics. Actual power generation is given in a percentage of the total installed capacity at the end of 2015. As observable, electricity feed-in from photovoltaic oscillates in day and night circles whith varying intensity depending on weather conditions. Solar power shows very strong performance gradients which is also clearly visible at morning and afternoon. Wind on the other hand is totally based on weather conditions and therefor no periodical behavior can be observed. As shown in the diagram drastic infeed fluctuations can occure from one to the following day. The average ouput percentage illustrated in the diagram is calculated by dividing the total produced electricity volume in the year 2015 by the installed capacity of wind and photovoltaic power which was installed at the and of 2015. It can be observed that on average only about 20 percent of the installed wind power capacity and 11 percent of the solar capacity is actually fed into the network. In comparison to thermal or nuclear power plants, availability from variable renewables therefore is much lower and consequently more installed capacities are necessary to be able to produce the same amount of electricity over time. Resulting from the large fluctuation range, higher flexibility of conventional power plants is getting more important to be able to react to the given requirements. Forecasting the uncertain actual power output is necessary in order to coordinate electricity supply as well as to sell the expected electricity volumes on the day-ahead market. However due to the difficult predictability of weather conditions, forecasts often vary from the actual power infeed and so positive and negative forecast errors are possible to occure. Adjustments of the already sold day-ahead volumes can be made via intraday trading as new information is gathered over time. A more detailed explanation regarding the effects of forecast errors on the German intraday market is provided in chapter 5.7.2.

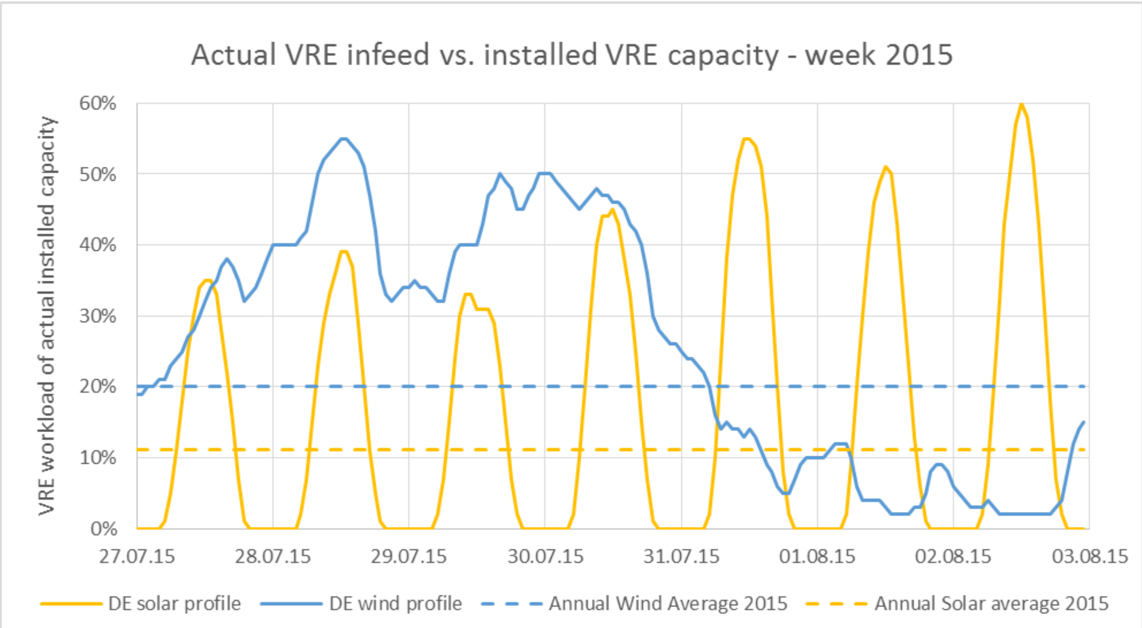

Figure 3.9: Actual VRE production profile in Germany for one week in 2015

3.3.3 Effects of variable renewables on the wholesale market

With an increasing share of renewable energy, increasing influence on the electricity wholesale markets is taking place and therefore market structures and price behaviors are changing. As previously discussed, variable renewable energy sources are characterized by high volatility and very low marginal generation costs which consequently affects spot and future markets. The most noticeable effects are decreasing electricity prices, a change in the base-peak price ratio and higher infeed volatility. In the following paragraphs a more detailed explanation of these effects is provided.

The main effect on the electricity market is a price reduction caused by overcapacities in the long term and also the broadly discussed merit order effect. Overcapacity is on the one hand the result of the existence of too many base-load power plants which were built in the first decade of the 21st century as a result of overly optimistic economic growth expectations. On the other hand overcapacities are caused by the very fast deployment of renewable energy production in the last ten years which did not allow the market participants and producers to adapt quickly enough. This means that new plants are added to the system instead of replacing older existing capacities. [15]

The Merit-Order effect is described as the price cutting effect to the electricity prices at wholesale level by increased generation of renewable energy. Through variable costs of near zero, renewable power plants displace conventional power generation from the merit order, which is illustrated in Figure 3.10. In the short term, power plant deployment is unchangeable and so in hours with high renewable energy feed-in the market price is determined by power plants with lower marginal costs. This consequently reduces the determined wholesale prices where supply meets demand. As observable, conventional power plants get shifted to the right and are no longer used to generate electricity. In a long term point of view, the merit order effect therefore causes the displacement of the expensive conventional power plants by the market entry of cheaper renewable generation, which consequently also reduces wholesale prices in the long run. [43]

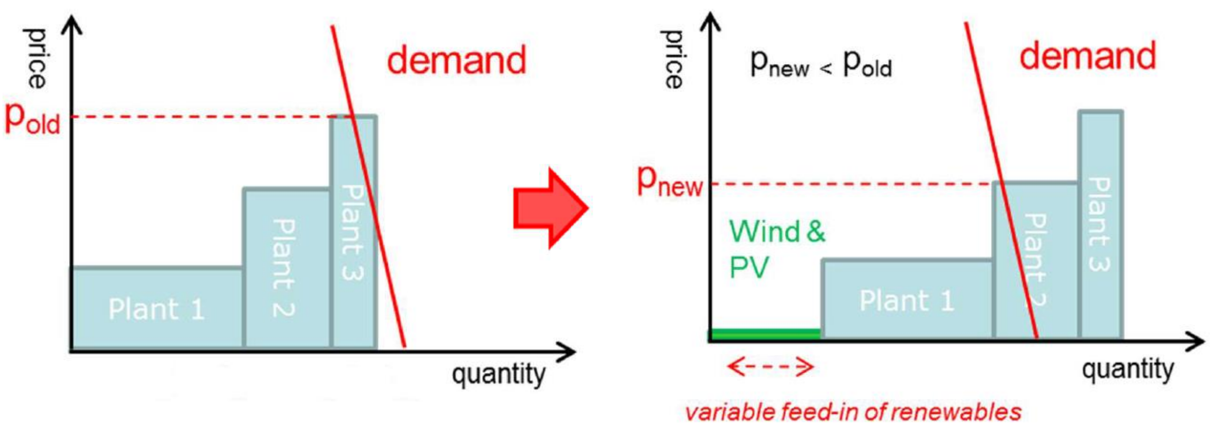

Figure 3.10: Merit Order Effect [74]

Variable renewable energy in some cases can furthermore be the cause of negative prices on the day-ahead and intraday market. This occurs only rarely when high inflexible power generation meets situation with low electricity demand while additionally high infeed from variable renewable energy sources. Inflexible power sources can't be shut down and restarted in a quick and cost-efficient manner and therefore it is sometimes less expensive to keep power plants online even when prices are negative for a short period of time. Renewable generation further intensifies this effect due to disadvantageous support schemes, acting as "must-run capacities" which do not react to oversupply or negative market prices by withdrawing production. However negative prices are softened ore even prevented by more flexible plants, as well by market coupling and increased cross boarder trading. For instance, in case of low or negative prices in Germany, surrounding market areas will import electricity until cross-border capacity is fully used or prices converge. [44]

Another form of price reduction is the so called peak shaving effect caused by high photovoltaic infeed at midday. As previously presented in Figure 3.4 the electricity wholesale price shows a strong correlation to the residual load which has to be generated by conventional power plants. In peak times between 8am and 8pm energy demand is high and therefore higher energy prices are expected based on the underlying merit order curve. Photovoltaic power plants counteract this price increase by their naturally behavior of supplying electricity during daytime and therefore reducing the residual load which as a consequence lowers the wholesale price. If the total installed photovoltaic capacity is high enough this can cause an inversion of base and peak prices which means that during the day when demand is high, the average price is lower than the 24 hour average. Instead of a price peak at midday, two peaks in the morning and evening are observable where high demand meets low photovoltaic infeed. This effect is illustrated in Figure 3.11 for the German market region. Due to the decreasing peak/base spread, storage facilities such as pumped storage hydro plants loose profitably.

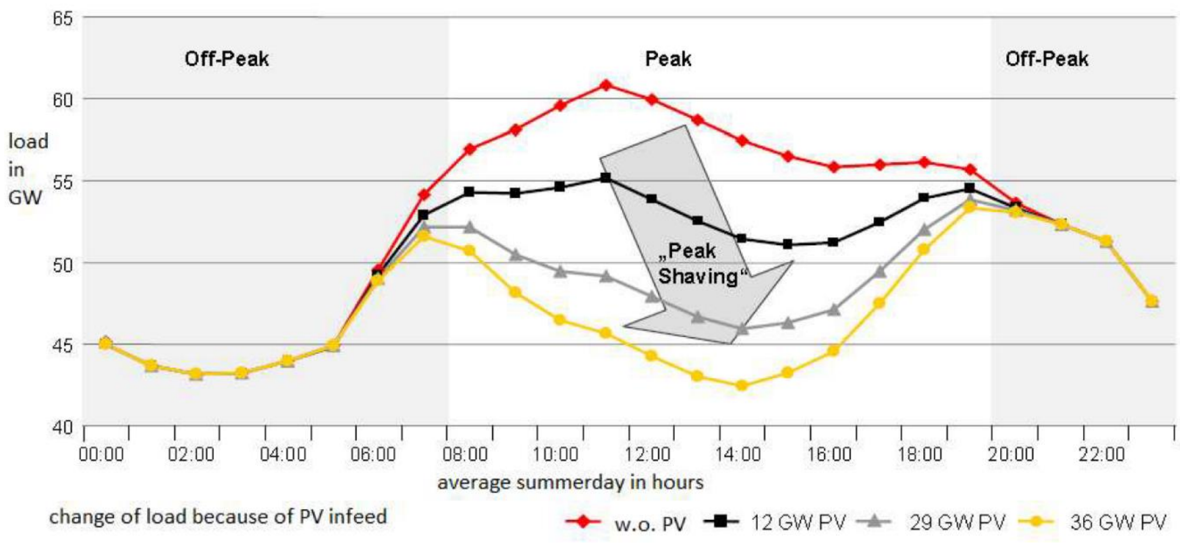

Figure 3.11: Peak shaving of residual load by increased photovoltaic infeed [73]

Looking at traded volumes, most of variable renewable energy is traded on the day-ahead market. This is on the one hand forced by mandatory day-ahead trading of certain renewable support schemes. However, also renewable energy which is sold via direct marketing is mainly traded on the day-ahead market to reduce price risks from an uncertain electricity feed-in in the long run [15]. Therefore the traded day-ahead market volume rises with an increasing share of renewable energy supply. Parallel, traded volumes on intraday markets also rise due to the high volatility and the requirement to adjust forecast errors between the gate closure of the day-ahead market and the point of actual delivery.

Intraday markets like EPEX Spot and Nordpool already have responded to the new market requirements to support variable renewable energy and therefore added new products to their available trading portfolio. This includes the introduction of 15 minute contracts which allow a more accurate modelling of steep productions ramps. Main reason for the introduction of 15 minute contracts is the steep production gradient caused by photovoltaic power plants. Furthermore the closing time for intraday trading is getting closer to the actual point of delivery. For example on the EPEX Spot intraday market, since 2015 trading continues until 30 minutes before delivery in Germany, France and Austria [45].

4 Data Documentation

4.1 Data Research and Collection

In order to provide statements about the developments of electricity markets, a representable data basis needs to be set up, which requires uniform market data of the respective market areas. In this thesis a time period of ten years is observed, which corresponds to the years from 2006 to 2016. The necessary resolution in which the time series have to be provided, differs regarding the various research questions. In order to determine possible long-term trends and structural changes, it is sufficient to examine market data on a monthly or annual base. Short-term fluctuations and seasonal influences are not of interest in this respect. On the other hand, if the short-term influence of variable renewable energy and the impact of prediction errors on the spot market is investigated, market data in hourly resolution needs to be evaluated. Market structures are primarily determined by the traded amount of electricity and the corresponding price. A major part of the work crating this thesis was research and procurement of market data for the various European electricity exchanges. In the following two paragraphs the sources used to create the database of time series on which this thesis is built up are presented.

Most electricity exchanges provide precise market data on their website, however only a 24-hour period can be observed at once, which is therefore not sufficient regarding long-term observations. If available, access to a complete database of market data is usually only provided to exchange participants or after payment. For this reason exchanges were contacted directly and market data covering EEX and Nordpool was provided free of charge to use in this thesis. The EEX data used includes the future market on a daily basis between 2012 and 2016, EPEX day-ahead and intraday data on an hourly basis for the years 2007 to the end of 2016, covering the German and Austrian market area including price and volume information. Furthermore EEX and EPEX data covering the German, French and Spanish market was obtained by monthly market reports [46] [47].

The provided Nordpool data covers the spot market on an hourly basis between 2006 and 2016 and traded intraday volumes starting from 2013. In addition, data is also accessible by annual reports [48]. The Scandinavian future market is organized by NASDAQ OMX. Price and traded volume information is available in monthly reports for the year 2007 to 2016 [49]. The Energy Exchange Austria (EXAA) provides full access to their spot market data on an hourly basis via their homepage from the year 2002 up to 2016 [50]. Czech OTE spot market data is also published on their homepage on an hourly basis from 2002 until 2016 [51]. The Czech future market is operated by PXE which provides market data in monthly reports [52]. Day-ahead data for the MIBEL (Spain and Portugal) market area can be accessed via the OMIE homepage for the years between 2007 and 2016 [53]. Information about intraday trading volumes was obtained by annual reports. The Iberian future market is operated by OMIP which provides market data online [54] as well as by the EEX [46]. Italian spot market data is available on the GME webpage [55]. Provided data includes the day-ahead market on a monthly basis starting from 2007 and annual traded intraday volumes starting from the year 2005. The Italian future market consists of data from GME´s MTE market [56], EEX Future market [46] and IDEX marketdata which is provided by Borsa Italiana in monthly reports [57]. Hungarian spot and future trading is operated by HUPX and market data is published in monthly reports since the starting of the exchange in 2011 [58].

In order to draw a reference to the increasing quantity of variable renewable energy production, information about annual installed wind and photovoltaic capacities in Europe was collected. This information was obtained from annual reports published by EurObserv'ER. [42] [40]. Data regarding the German wind and photovoltaic infeed volumes were taken from Open Power System Data [59], consisting of forecast and actual infeed volume in an hourly resolution, originally published by the German transmission system operators. German load profile data was taken from the ENTSO-E [60]. Furthermore, commodity prices were collected to be able to draw a short comparison to the electricity price. Price information for coal, natural gas and oil was obtained by the German Federal Office for Economic Affairs and Export Control [61]. Monthly prices for the European emission allowances EUA were provided by EEX.

4.2 Final Database

All time series were put together in uniform databases in different resolutions depending on data availability. When calculating daily series to monthly and yearly values, volume was summarized and for price information the arithmetical average was calculated for each month/year. In scolded years, the 29th of February has been omitted. In some cases several competing exchanges are operating in the same market area, therefore regarding values of different exchanges were summarized to regional series to provide better representation and comparability. The scope of data handled by this thesis is stated in the following tables. Market data in form of time series is available without interruption until 2016, beginning in with the year mentioned in the regarding panels, in a resolution according to the column header.

As apparent in Table 1, the actual trading prices of the front year base contracts are used to represent the future market price of electricity at a certain point of time. This applies with exception of the Nordic and Czech future market due to missing availability of corresponding price information. In both cases the average trading price of electricity futures was calculated by dividing the total exchange's nominal turnover by the total electricity trading amount of a corresponding time period. Some exchanges also offer a breakdown into exchange traded and OTC-cleared future volumes, however only the summarized volumes were further investigated in this thesis since this was the only information available for all observed market regions. In Table 2 all used market data concerning day-ahead trading is listed. Table 3 covers intraday market data and shows that price information for intraday market is very spare, while traded volumes for different intraday markets are at least available in an annual resolution. In Table 4 additional data is listed which is used to give a qualitative insight on the short-term effects of variable renewable energy production in Germany in chapter 5.7.

			daily	monthly	yearly
Day-Ahead Market	Price	EPEX Spot Day-ahead auctions DE/AT	2006	2006	2006
		EXAA SPOT Austria bEXAbase	2006	2006	2006
		EPEX Day-ahead France	2015	2009	2009
		GME IPEX Italy PUN	x	2007	2007
		Nordpool Elspot Base System	2006	2006	2006
		OMIE Day-ahead Spain	2007	2007	2007
		OMIE Day-ahead Portugal	2007	2007	2007
		OTE Czech Day-ahead	2006	2006	2006
		HUPX Hungary Day-ahead	x	2012	2012
	Traded Volume	EPEX Spot Day-ahead DE/AT	2006	2006	2006
		EPEX Spot Day-ahead France	2015	2008	2009
		GME IPEX Italy Spot-market	x	2007	2007
		Nordpool Elspot Nordic System	2006	2006	2006
		OMIE Day-ahead Spain	2007	2007	2007
		OMIE Day-ahead Portugal	2007	2007	2007
		OTE Czech Day-ahead	2006	2006	2006
		HUPX Hungary Day-ahead	x	2011	2011

Table 1: Database - Day-ahead Market

			daily	monthly	yearly
Intraday Market	Price	EPEX SPOT DE/AT Intraday Continuous	2007	2007	2007
		EPEX SPOT France Intraday Continuous	2015	2015	2015
	Traded Volume	EPEX Spot Intraday DE/AT	2007	2007	2007
		EPEX Intraday France	2015	2015	2015
		GME Italy Intraday MA/MI	x	x	2005
		Nordpool Elbas Intraday (SE,NO,FI,DK,EE,NL,BE)	2006	2006	2006
		OTE Czech Intraday	2006	2006	2006
		OMIE Intraday Spain+Portugal	x	x	2007

Table 2: Database - Intraday Market

			daily	monthly	yearly
Future Market	Price	EEX Power Derivatives DE/AT Y+1	2012	2010	2007
		Nasdaq Nordic Power Futures (avg. price)	x	2007	2007
		IDEX Italy Futures Y+1	x	2012	2011
		OMIP MIBEL Spain/Portugal Future Exchange Y+1	x	2007	2007
		PXE Czech Power Futures (avg. price)	x	2008	2008
		HUPX Physical Futures Y+1	x	2012	2012
	Traded Volume	EEX Futures DE/AT exchange traded	2012	2010	2005
		EEX Futures DE/AT OTC cleared	x	2010	2005
		Nasdaq Power Futures exchange traded in Germany	x	2013	2013
		EEX Futures France exchange traded	x	2010	2009
		EEX Futures France OTC cleared	x	x	2009
		GME Italy MTE Futures exchange traded	x	2009	2009
		GME MTE Futures OTC cleared	x	x	2010
		IDEX Italy Futures	x	2009	2009
		EEX Futures Italy exchange traded	x	2014	2013
		EEX Futures Italy OTC cleared	x	x	2013
		Nasdaq Power Futures Nordic exchange traded	x	2007	2007
		Nasdaq Power Futures Nordic OTC cleared	x	2007	2007
		OMIP MIBEL Futures Spain+Portugal	x	2007	2006
		EEX Futures Spain	x	2015	2014
		PXE Czech Power Futures	x	2008	2008
		HUPX Physical Futures exchange traded	x	2012	2009
		HUPX Physical Futures OTC cleared	x	2012	2009

Table 3: Database - Future Market

		hourly
RES Analysis Germany	EPEX SPOT DE/AT Intraday continuous price	2015
	EPEX SPOT DE/AT Intraday continuous - traded volume	2015
	EPEX Spot Day-Ahead auction price DE/AT	2006
	German load profile	2015
	German wind energy forecast	2015
	German photovoltaic energy forecast	2015
	German actual wind production	2015
	German actual photovoltaic production	2015

Table 4: Database - Detail Analysis on Renewables

5 Data Analysis and Results

In this chapter the collected market data time series are illustrated and analyzed in various diagrams to provide insights on the dependencies, influencing factors and trends regarding price and volume information of traded electricity on the European electricity markets. In order to provide better comparability in the sub-section 5.3 to 5.5, all traded volumes are set in relation to the total electricity demand in 2012 of the regarding market region. The used demand values were taken from Eurostat [62] and are shown in Table 5.

Demand 2012	DE/AT	Austria	Italy	Nordic	Mibel	France	Czech	Hungary
TWh	587,9	61,1	297,7	373,5	286,6	433,7	56,0	35,2

Table 5: Electricity Demand 2012

5.1 Market Overview in 2016

Data analysis starts with a snapshot of the current market situation in 2016. As illustrated in Figure 5.1 the composition of electricity wholesale markets differs significantly between the European market regions. Markets differ in terms of liquidity as well as regarding the varying ratios between market segments. Churn rates are frequently used as an indicator of market liquidity. A common definition of a churn rate is the volumes traded through exchanges and brokers expressed as a multiple of physical consumption [63]. Traded volumes in Figure 5.1 are set in relationship to the total electricity demand in 2016 of each region and therefore churn rates for can be read directly from the diagram. However, due to limited data availability no long term trends regarding market composition and churn rates can be provided.

The German market region by far shows the highest overall market liquidity with a churn rate of nearly 15. Liquid markets are also the Nordic market with a churn rate of 4.5 as well as France and Italy with rates between 3 and 4. Spain shows a churn rate of 2 while in Central Eastern Europe only a value of 1.6 can be reached.

Looking at the ratio between spot market, future market and over the counter trading markets also show significant differences. In Germany about 70 percent of all traded volume is settled over the counter from which one quarter gets cleared by an exchange. Spot market covers about half of the regions electricity consumption while future traded volume via exchanges amounts to about 360 percent of the total demand, which therefore is the most liquid future market in Europe. The Nordic region shows a very liquid spot market with a traded volume of more than 90 percent of the total electricity consumption. Striking on the Nordic region is also the fact that all bilateral traded volume is cleared by an exchange. Over the counter and exchange traded future volumes show about similar values.

In France OTC trading is predominant which amounts to about 70 percent of all traded volumes like in Germany. Spot market trading only covers about 25 percent of the French consumption which therefore states the lowest spot liquidity in central Europe. In Italy up to 70 percent of the country's consumption is traded on the spot market. A mayor part of the traded future volume in Italy is settled over the counter. In Spain also 80 percent of consumption is traded on the spot market, while future trading mostly takes place over the counter. In Central East Europe OTC trading is dominant, exchange trading only covers a very small amount of the traded volumes.

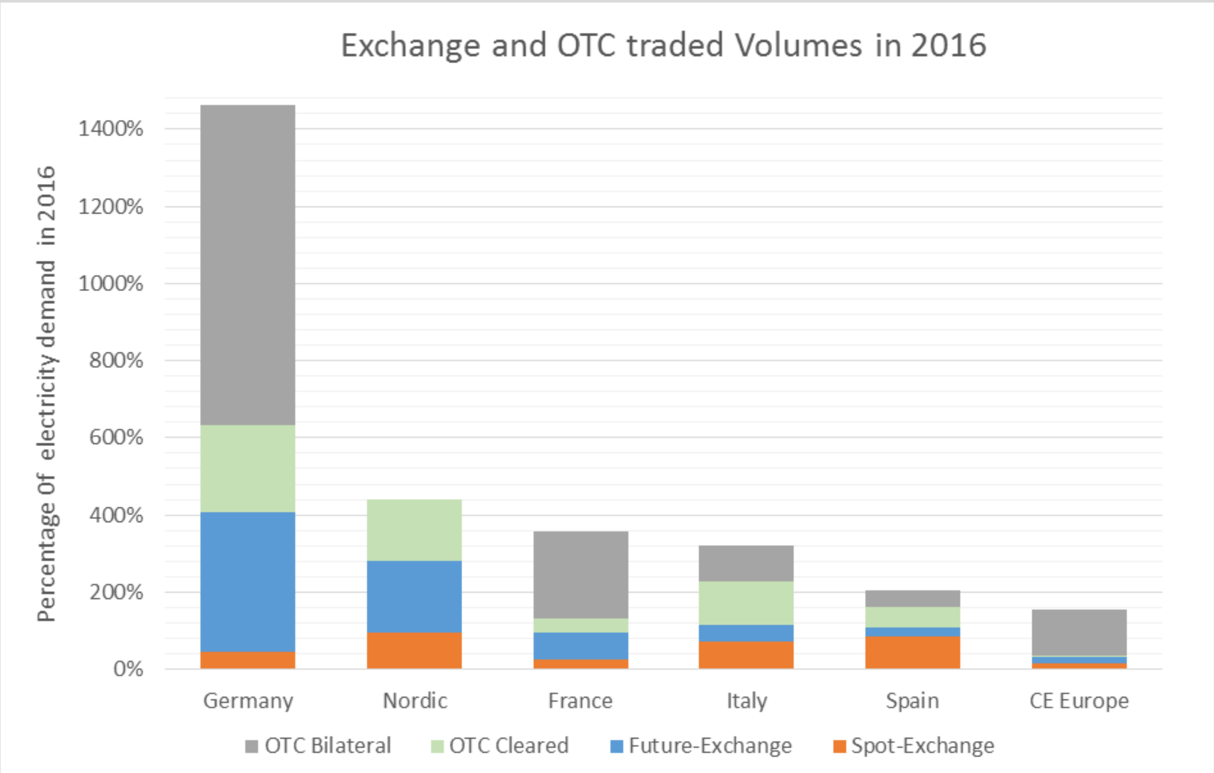

Figure 5.1: Exchange and OTC Volumes in 2016 - [29]

5.2 Electricity Demand & Commodity Prices

Hourly electricity reference prices are determined on day-ahead markets in daily trading auctions where supply meets demand, as previously explained in chapter 3.2. Electricity demand mainly depends on the economic situation as well seasonal influences and shows only low short term reactions on the price level. The supply side is represented by different power plants ranked in the merit order curve, which therefore depends on underlying commodity prices as well as total installed capacities, particular from available electricity production from variable renewable energy sources. In the following paragraphs the development of European electricity demand and commodity prices is discussed.

In Figure 5.2 the trend of electricity consumption over the past ten years is illustrated. This data was obtained from Eurostat [64] and set in relation to the average annual consumption over the observed ten year period of each region to provide better comparability. The Nordic region is presented in this graph by summarized consumption from Norway, Finland, Sweden and Denmark. It can be concluded that electricity demand showed a downward trend over the observed decade. Most striking is the drastic demand drop in 2009 due to the financial crisis and the consequent recession. Demand recovered significant in the following year but since then constant decrease of electricity consumption took place until 2014. Italy and the Iberian region show a particularly pronounced decline especially between 2012 and 2014. French electricity demand shows high volatility mainly caused by its high share of electric heating and the therefore strong impact of annual temperature levels.

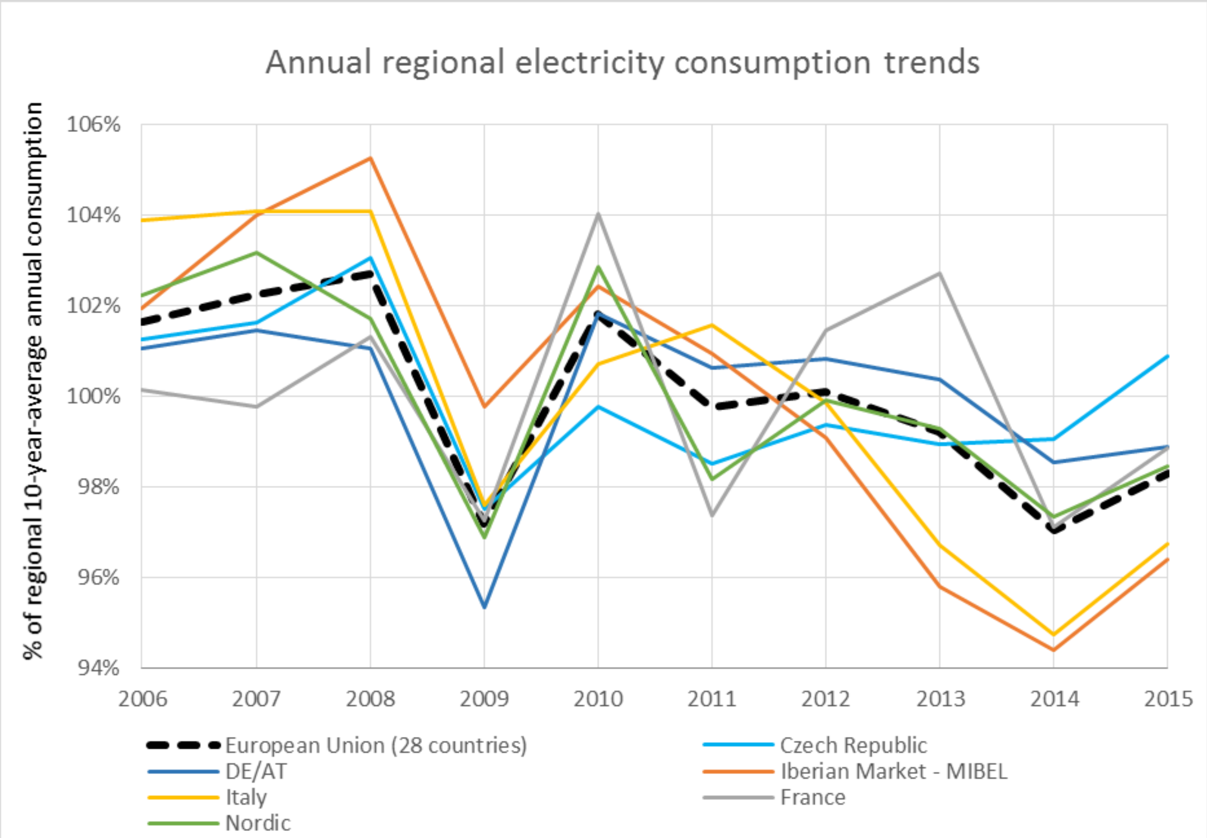

Figure 5.2 Trend of Annual Electricity Demand

Figure 5.3 shows the development of commodity prices over the past decade. The years 2007 and 2008 are marked by a price rally regarding all commodities, followed by a huge shock caused by the financial crisis. To the year 2012 prices of oil, gas and coal show a constant recovery. However since 2012 coal and gas prices keep decreasing and have reached levels below the ones after the financial crisis in 2009. Oil price suffered an explicit price drop between 2014 and 2016 resulting from a tight oil boom in the US and the recovery of production capacity in the Middle East. In contrast the price for European Emission Allowances keeps on going downwards since the financial crisis due to lack of demand, renewable policies and the use of international emission credits [65].

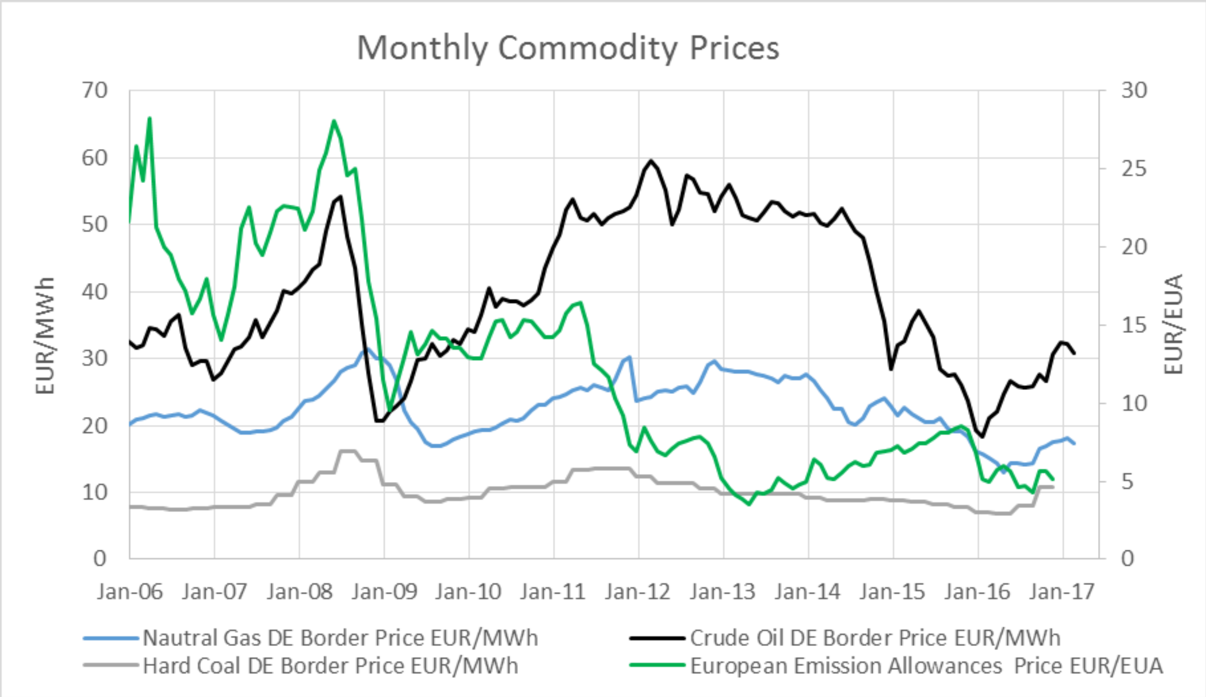

Figure 5.3: Commodity Price Development

5.3 Day-Ahead Markets

This chapter consists of an investigation of the day-ahead electricity price development including an analysis of price structures changes regarding volatility and base-peak spreads. Furthermore the development of traded volumes on various European day-ahead markets is presented.

5.3.1 Price development

Figure 5.4 shows the development of the wholesale day-ahead market prices in Europe over the past decade. Looking at overall trends in Europe it can be observed that prices in 2006, when electricity prices reached the highest levels since 2000, decreased noticeably until summer of 2007 due to mild temperatures, low emission prices and good hydro power conditions. At the end of 2007 electricity prices then showed a steep increase in line with the underlying commodities as presented in Figure 5.3. The high price level was interrupted at the end of 2008 by the financial crisis which led to cheaper commodities and a drastic demand reduction due to economic recession. Between 2009 and 2012 again in line with coal and gas prices, the electricity price level recovered, but then the following time period until 2016 was again marked by a constant price decrease reaching the lowest prices since more than ten years.

Looking more in detail, many positive and negative price peaks occurred as well as further regional peculiarities which will by described in the following paragraphs. It can be observed that Italy shows significantly higher prices than Europe. This is mostly caused by its high share of gas fired electricity production and an overall tight supply situation [66]. Due to low demand, increased cross boarder trading and a remarkable risen share of photovoltaic, over the past five years the Italian electricity price came nearer to the European average. In contrast to Italy, the Nordic market is less dependent of commodity prices due to a very high share of hydro power.

When going through the timeline starting in 2006 a first price peak on the German market can be found in August 2006 which resulted from a heatwave causing low hydro power availability and throttling of thermal power plants. Due to mild temperatures in 2007 and 2008, high water reservoir levels met with low demand on the Nordic electricity market and therefore each time showed significant price drops. In July 2007 the mild weather conditions in the north were perceived as a heatwave in Italy which led to a price peak by the increased electricity demand for cooling. Due to low nuclear power availability in France and Germany in November 2007 peaked again. In September 2008 a last significant price peak occurred before the drastic fall from the financial crisis. On the Nordic market this peak was mainly caused by the limited availability of nuclear and hydro power plants in Sweden and Finland and additionally the breakdown of an interconnector to Norway. Spain and CWE markets also suffered from low nuclear and hydro availability and further expectations of a drop in lignite production put upward pressure on prices. The peak in October 2009 on the French market can be explained by a supply shortage due to limited nuclear power plant availability.

In 2010 the two price peaks in the Nordic market can be attributed to low hydro levels and high heating demand due to periods of very cold temperatures. In contrast the Spanish market showed a monthly average price of only 20€/MWh in March 2010. This is because of high hydro and wind production while demand has not yet fully recovered from to the financial crisis. In January 2012 Europe suffered from extraordinary cold weather which resulted in a significant price peak. Another price peak was caused by a heat wave in August of the same year in Italy due to cooling demand. In contrast, the Nordic price dropped because of very high supply from hydropower. In 2013 and the beginning of 2014 the Spanish electricity price shows great fluctuations mostly caused by weather conditions which led to significant supply shifts from wind and hydro power. Similar to the heat wave in august 2012, the prices were also affected by a heat wave in august 2015.

Between November 2015 and February 2016 the weather was milder than usual in the whole CWE region, reducing heating related demand for electricity. In the same period fossil fuel prices fell to a several year low, impacted marginal electricity generation costs and therefore also contributed to the downward trend on wholesale electricity prices. In January 2017 periods of cold weather in most of Europe significantly increased the demand for electricity. Furthermore low nuclear capacities in Germany, low wind and solar generation and also low hydro availability caused by the ongoing dry period and freezing temperatures have all added to the upward pressure on electricity prices. In February and March of 2017 however, temperatures rose to higher levels than usual and prices again decreased significantly.

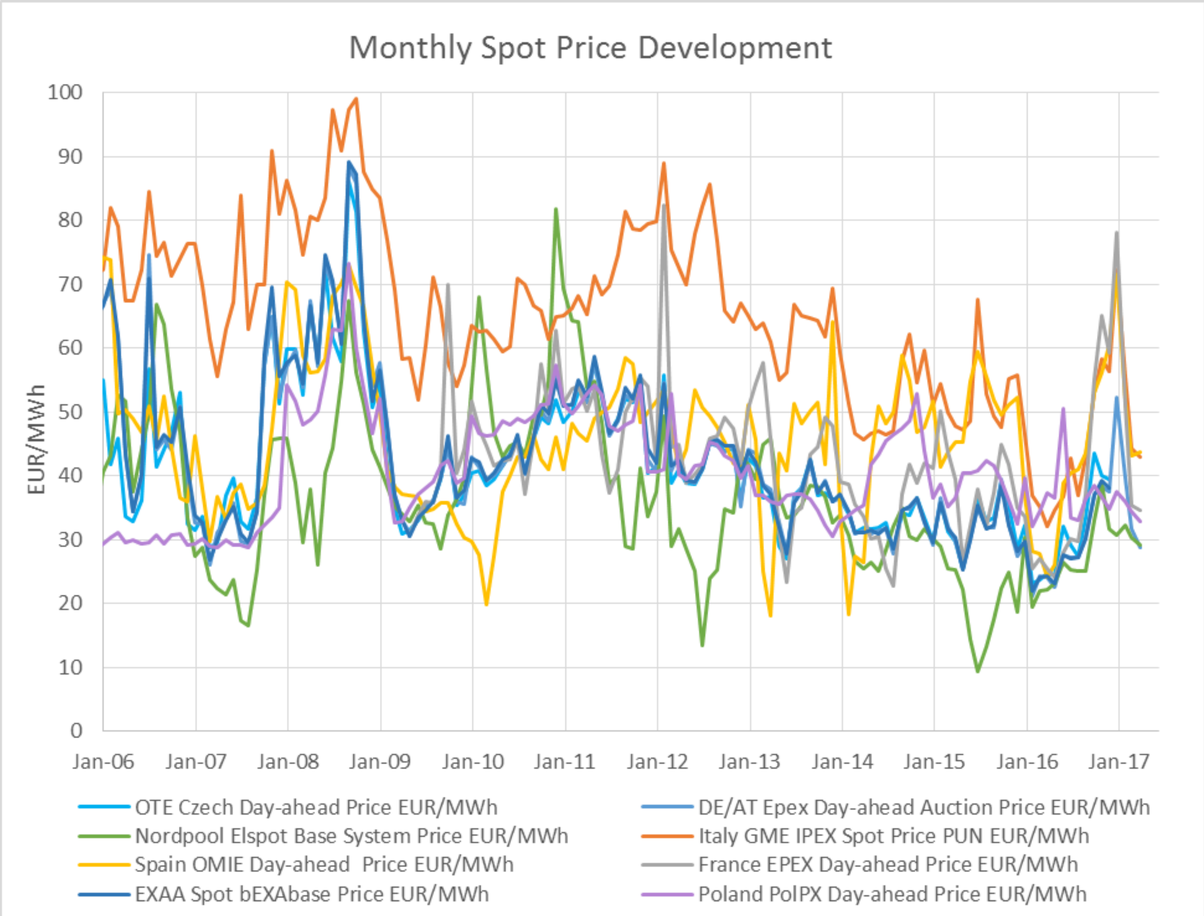

Figure 5.4: Wholesale Electricity Spot-Prices – monthly

5.3.2 Volatility Development

Figure 5.5 shows the development day-ahead base price volatility over the past decade for different European market regions. Volatility is a measure for price variability and fluctuation and in this case states the average day-ahead price change between two following calendar days. A more detailed explanation of the calculation used can be found in formula (1). The diagram therefore represents the quarterly average of the absolute difference between day-ahead base-prices of two following calendar days in the regarding quarter, in relation to the average spot price of the past 365 days. The therefore drawn reference to the 365-day average spot price level provides better comparability between the different observed market regions, as well takes the overall spot price development into account.

$$Volatility_{Quartal} = average_{Quartal}\left(\frac{|S_t - S_{t-1day}|}{S_{365}}\right) \quad (1)$$

Volatility calculations based on hourly price information was not possible due to limited availability of market data regarding the various European exchanges. An illustration in a monthly resolution instead of the used quarterly averages was discarded to provide better legibility. The diagram indicates that there is no general volatility trend observable which applies to all analyzed market regions.

The German/Austrian and Czech market show a strong correlation as already stated in Figure 5.4. Volatility levels on the German market between 2006 and 2010 were the highest in the European comparison with an extraordinary high fluctuation band and volatility peaks in the fourth quarter of most years. However an overall slightly decreasing trend can be observed. The very high volatility in 2006 was mainly caused by extraordinary weather conditions in summer which resulted in low thermal power plant availability and high spot prices. In winter 2007 prices peaked again due to very low nuclear power availability in Germany and France, which also led to very high price volatility. In 2010 when the CWE market coupling took place German and Czech volatility level remained on a steady and low until 2012. From the beginning of 2012 to the end of 2014 a significant volatility increase can be observed but then remained stable until 2016. The daily Italian volatility levels remained on a constant level with the exception of a small reduction in 2010. The Spanish market until 2012 was marked by overall low volatility levels but then volatility increased at the same time as in the German market area. Since 2013, strong seasonal pattern can be observed with volatility peaks in the first quarter of every year. The extraordinary peaks in 2010, 2013 and 2014 were caused by very low electricity spot prices due to high availability of hydro power and variable renewable energy sources. The Nordic market shows the lowest price volatility in the European comparison. Volatility level remained constant over time with some exceptions in 2010, 2012 and 2016 which were all caused by extraordinary weather conditions resulting in different hydro power generation behavior and price fluctuations.

An explicit link between the increasing share of variable renewably energy generation and day-ahead price volatility on a daily basis cannot be observed. On the one hand the volatility increase on the German market from 2011 to 2013 fits to the drastic increase of simultaneously installed solar capacity, however similar solar installations in Italy didn’t influence the volatility behavior. Also the strong increase of wind power in Germany from 2014 to 2016 showed no change in volatility. All occurred peaks were exclusively caused by limited availability of supply mostly due to extreme weather conditions.

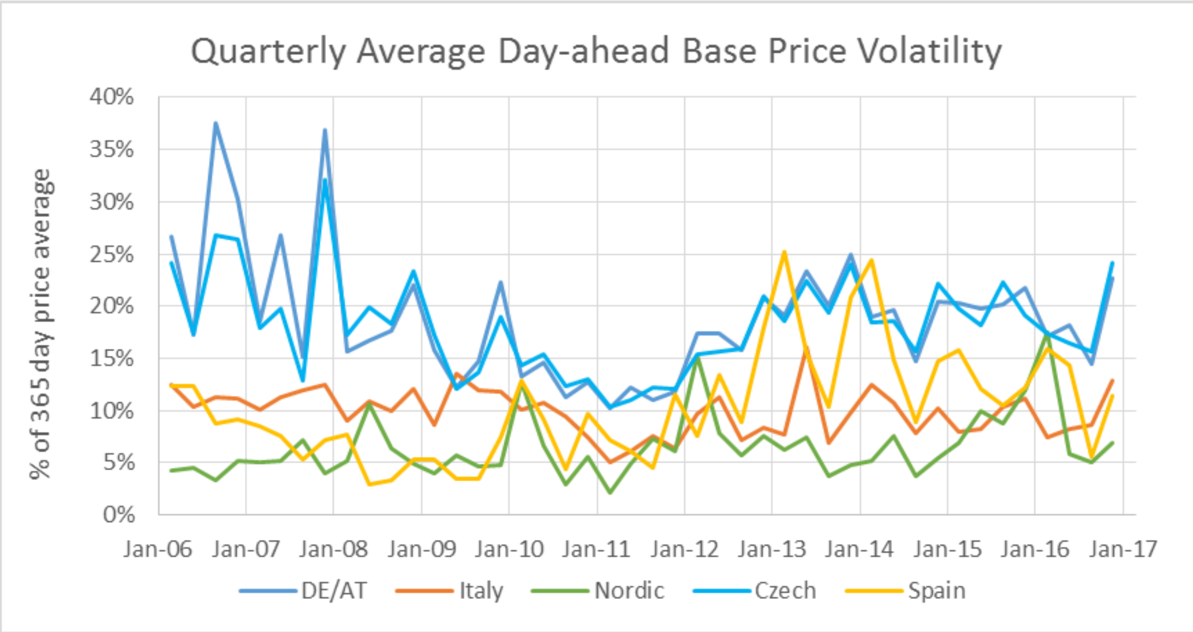

Figure 5.5: Quarterly Average Day-Ahead Price Volatility

5.3.3 Base-Peak Spread

The daily base price states the hourly price average of each calendar day from 00:00 to 24:00 o'clock. Peak prices on the other hand represent the average spot price only between 08:00 and 20:00 o'clock, and therefore cover the time period of higher electricity consumption. Usually due to the higher demand, peak prices are consequently higher than base prices. In Figure 5.6 the development of monthly average base-peak price spreads is illustrated. Depending on the market region and the corresponding electricity generation structure different trends can be observed. Most significant changes occurred on the Italian market. Price spreads between 2006 and 2009 were very high in the European comparison and also showed high volatility. As presented in Figure 3.7, between 2009 and 2013 a drastic increase of solar power capacity was installed which resulted in significant price structure changes. The peak price reducing effect of photovoltaic electricity generation is illustrated in Figure 3.11. Price spreads until 2012 remarkably decreased and since then show strong annually repeating price patterns. This annual patterns are on the one hand resulting from a usually higher electricity demand during winter and on the other hand lower infeed from photovoltaic power at the same time.

Since 2012, monthly Italian peak price averages in summer sometimes are even lower than the base prices. Similar developments applies to the German and Czech market. However the changes in price structure here are not as pronounced as in Italy. Price spread in Spain in 2006 already started at a low level but further decreased until 2009 as a result of a rising share of photovoltaic generation. In contrast the Nordic price spread hardly shows any difference between base and peak times, resulting from an electricity generation mix mostly based on hydro and nuclear power. This price behavior is particularly pronounced in Norway, which generates nearly 99 percent of its electricity demand by hydropower [67].

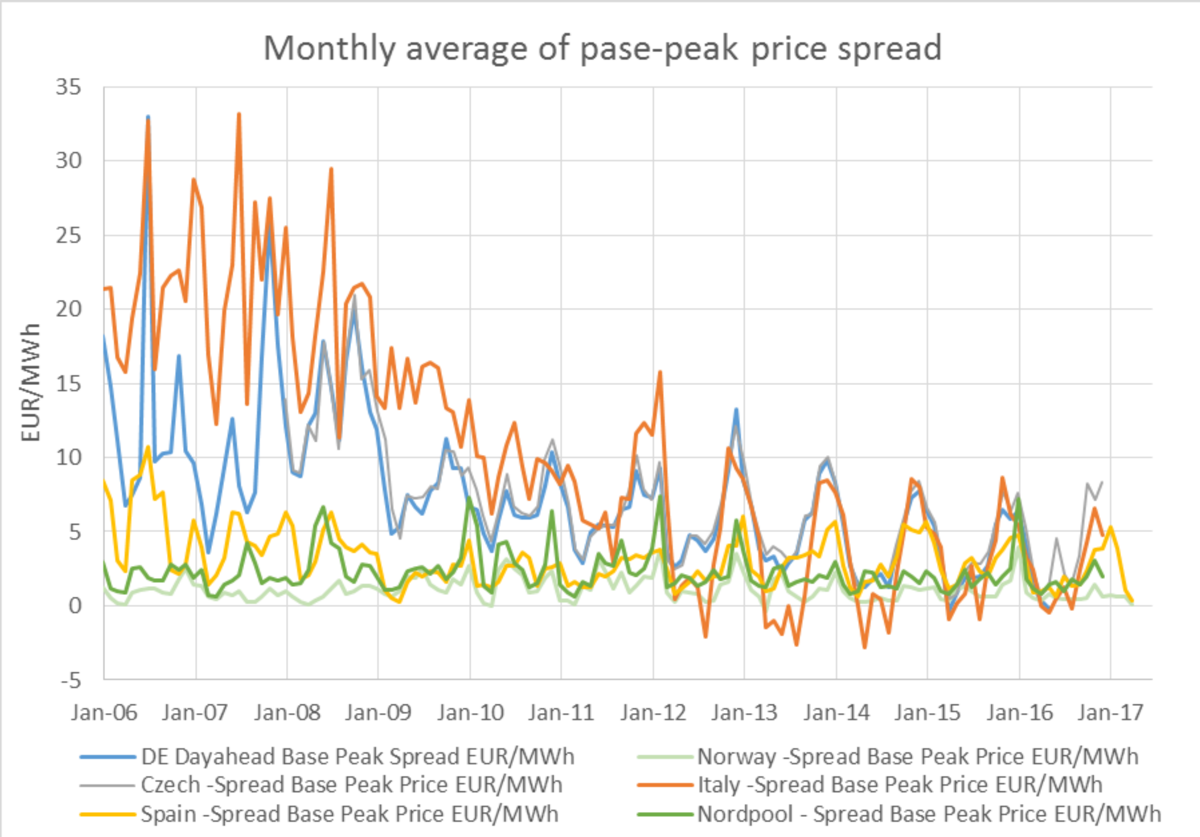

Figure 5.6: Base-Peak Price Spread - monthly average

Figure 5.7 shows the number of monthly occurred base-peak price inversions over the past decade. Findings from Figure 5.6 can be applied to this diagram as well. Again most striking is the drastic increase of price inversions on the Italian market starting in 2011. Similar development can be found in Germany, however price modification here is more uniform over a longer time period but nevertheless nearly catches up to the Italian region in 2016. Different behavior can be observed on the Spanish market. The monthly number of price inversions stays constant over the past decade regardless of the additionally installed photovoltaic capacity. Furthermore the Spanish region didn't show annual repeating patterns from season dependent sunshine intensity until 2015. In contrast to the Italian and German market, the Spanish and Nordic areas already show minor price inversions in some months in 2006.

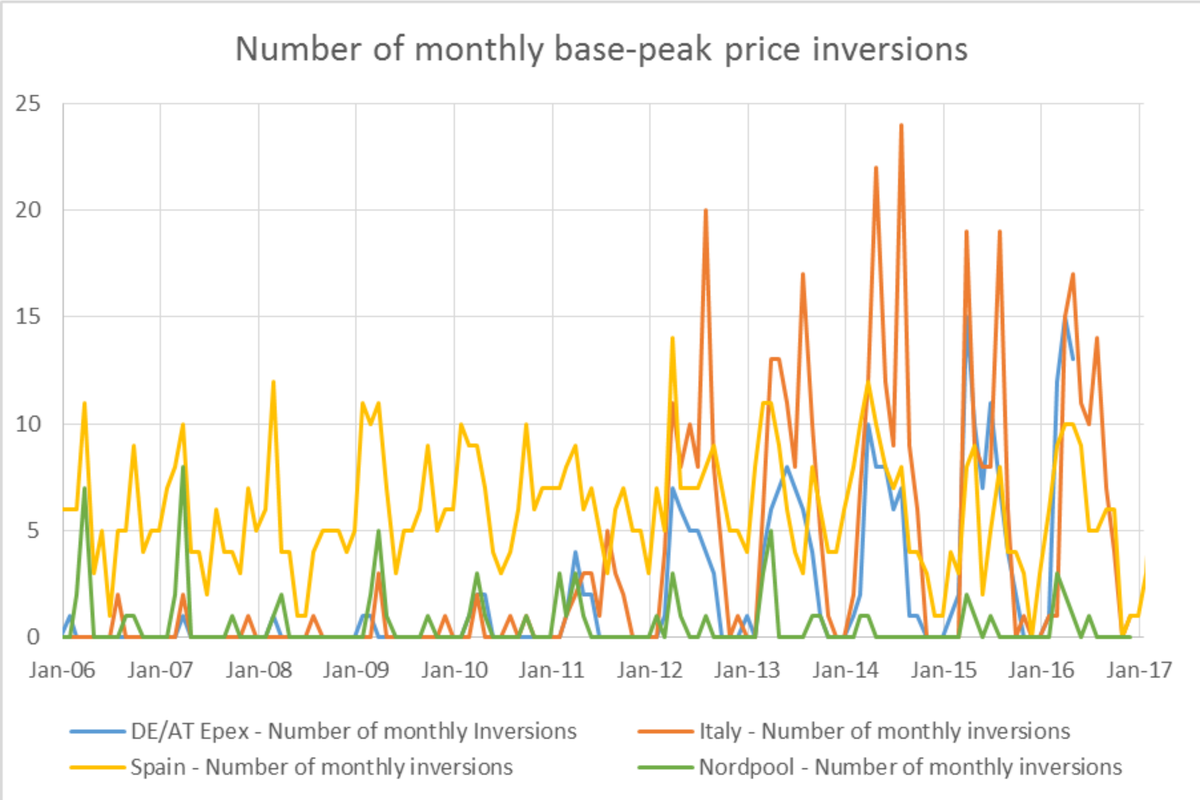

Figure 5.7: Number of monthly Base-Peak price inversions

5.3.4 Negative Prices

Hours with negative day-ahead prices only rarely occur when low demand meets inflexible high generation with additional high infeed from wind and photovoltaic. The development of negative priced hours per year on the German and Spanish day-ahead market can be observed in Figure 5.8. On the Nordic and Italian market area negative prices so far have only barely or not appeared at all in the past. For the Spanish market area electricity prices of 0 EUR/MWh are counted as negative due to a downward price cap which prevents negative values. It can be observed that in Germany negative first occurred in 2007 and increased until 2010 where negative prices then got reduced by implementing market coupling with France and the Nordic area. Due to the still rising share of variable renewably energy sources, the number of hours with negative day-ahead prices continued to increase. A decreasing effect is also dedicated to the adaption renewable support schemes from fixed feed in tariffs to market premium models. Similar price behavior applies to the Spanish market. Market coupling to Portugal (SWE) in 2010 and to the North Western Europe (NWE) in 2014 reduced the number of negative prices as well as a drastic change-over regarding renewable support schemes in 2013.

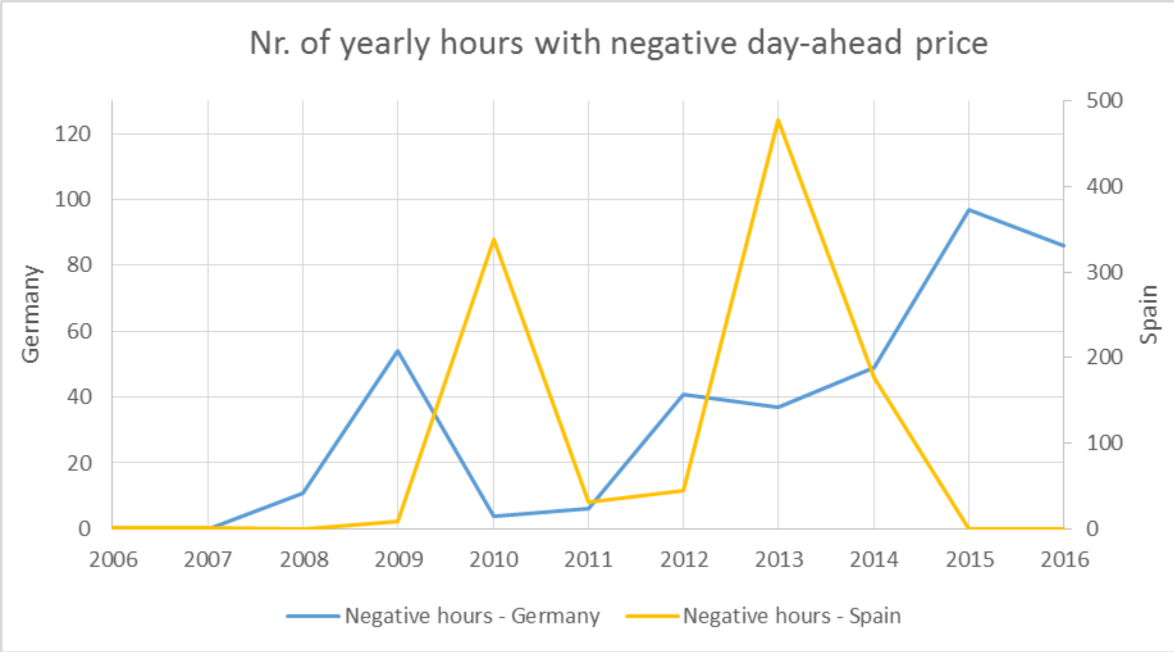

Figure 5.8: Number of hours with negative day-ahead prices per year

5.3.5 Traded Volumes

Figure 5.9 shows the development of annual traded volumes on the different European electricity exchanges. To provide a better comparison between the different exchanges, traded volumes are set in relation to the annual electricity demand in 2012 of the associated region which can be found in Table 5 on page 27. The diagram therefore also states the market liquidity in the different exchanges [68].

A constant trend towards growing volumes clearly can be observed. The only exceptions are Italy and the Iberian region caused by a weak economy situation and therefore overall decreasing electricity demand until 2014 [29] [56]. Since then, traded volumes also started to grow in both areas due to a recovering economic environment. Highest day-ahead market shares and therefore liquidity can be found on the Nordic, Iberian and Italian market regions. The EPEX Spot in the German and Austrian region shows a strong growth since 2009 which correlates with the increased share of variable renewable energy. From 2009 to 2015, traded EPEX spot market volume nearly doubled. Czech also shows a remarkable growing trend. The strongest increase occurs in the Hungarian region mostly because of the ongoing establishment of the very young HUPX exchange and strong economic growth. French volumes also show slightly growth but remains at low levels caused by the high share of OTC trading. EXAA in Austria stagnates at low share because of the much more popular EPEX which operates in the same region.

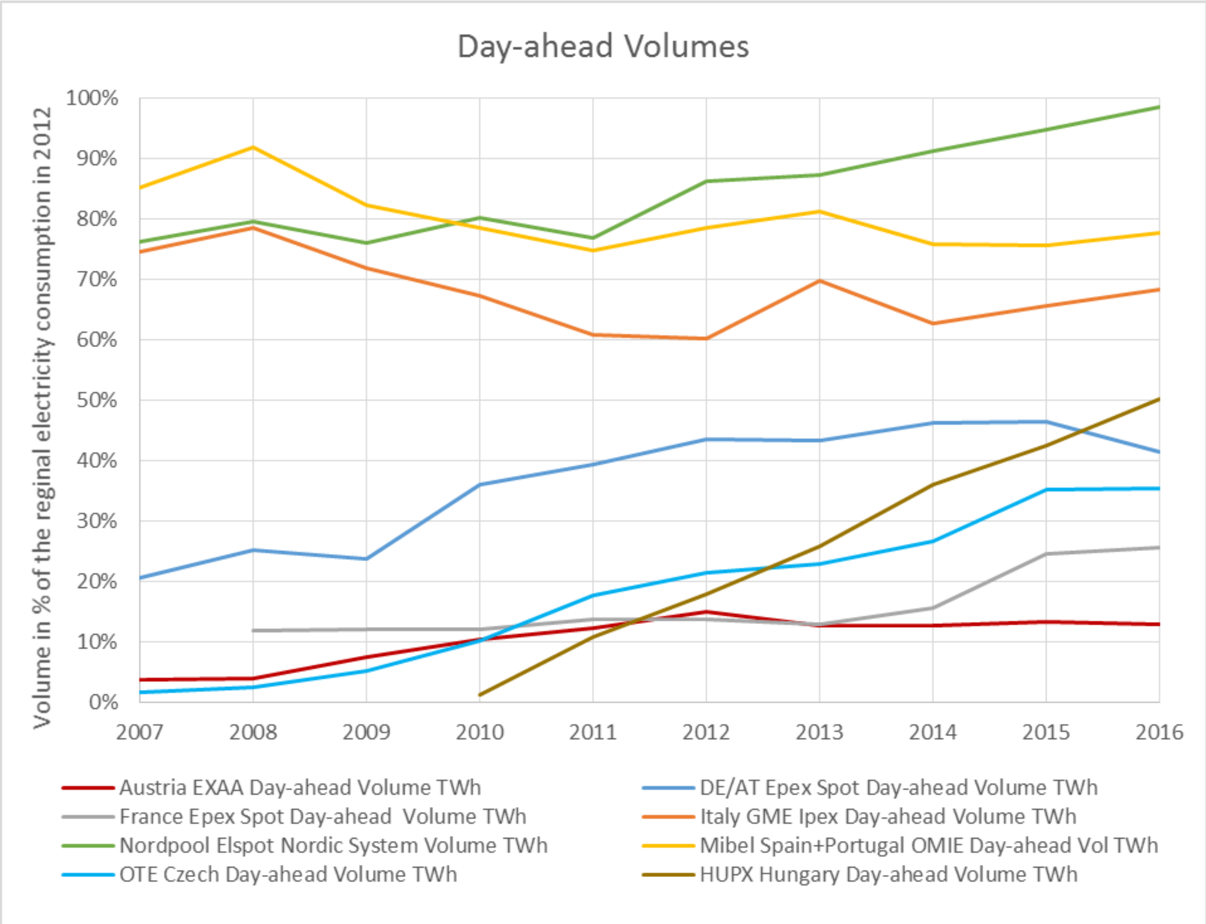

Figure 5.9: Annual Day-ahead Volumes in Europe

5.4 Future Markets

5.4.1 Risk Premium

Prices on the future market represent the expected value of spot prices at a specific time of delivery and are therefore strongly oriented to the day-ahead prices analyzed in chapter 5.3.1. However, future prices are usually higher than the expected spot price, whereby this price difference is referred to as a risk premium which can be interpreted as a compensation of bearing the spot price risk. In order to provide an insight on future markets developments, progress of risk premiums on different future markets over time are compared in Figure 5.10. The illustrated risk premiums are ex-post risk premiums of year base future contracts with a delivery in the following calendar year. The ex-post risk premium P is the difference between the actual future price F at time t for a contract with delivery at time T and the actual spot price S at time T, which is illustrated in formula (2). [69]

$$P(T) = F(t,T) - S(T) \quad (2)$$

Therefore ex-post premiums can only be calculated after delivery, when de actual spot price at the time of delivery *T* is known. This means for example the risk premium for the year 2016 is calculated by the average trading price in 2015 of a year-contract with delivery in 2016, subtracted by the average day-ahead price in 2016.

Figure 5.10 illustrates the development of risk premiums from 2008 to 2016. Until 2012, the diagram shows very high volatility caused by the drastic spot price changes during the financial crisis. A negative risk premium indicates that spot prices were much higher than expected which was the case in 2008 when commodity prices and demand pushed electricity prices on the spot markets. The remarkable high risk premium for year futures in 2009 results from the price drop after the financial crisis. In 2010 and 2011 spot prices recovered noticeably and therefore risk premiums remained very low. At the beginning of 2012, the rising trend of spot prices turned into a steady decrease until 2016. It can be observed that risk premiums show a constant decreasing trend since 2012. However this statement is only valid for front-year future contracts with a delivery period of one year. Furthermore the Nordic market has to be taken as an exception because instead of the year contract price the average price for all traded future contracts including month and quarter contracts has been used for calculating the market premium due to limited data availability. Nordic market shows slightly different behavior regarding the risk premium development. Electricity prices were more dependent from hydro power generation and therefore less influenced by the financial crisis. Due to limited data availability no analysis for month or quarterly future contracts could be conducted on any market.

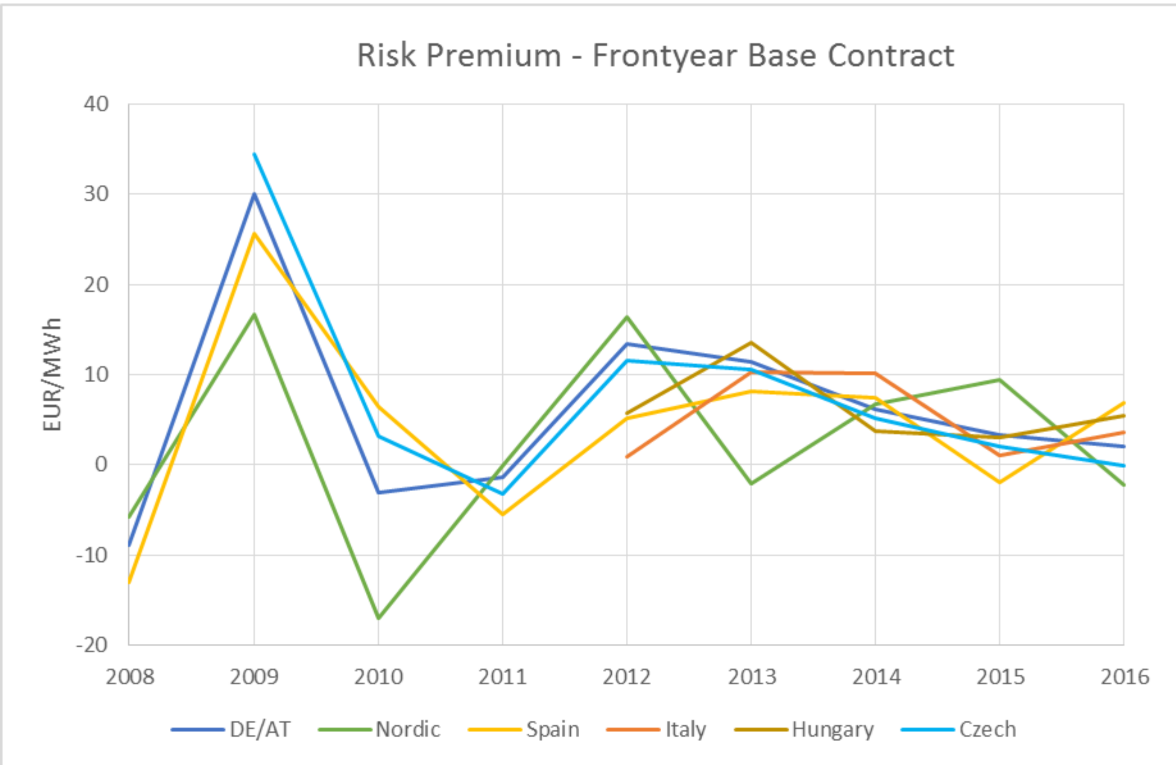

Figure 5.10: Risk Premium Development

5.4.2 Traded Volumes

In Figure 5.11 the development of future traded volume in different European regions is shown. To provide a better comparison between the different exchanges, traded volumes are set in relation to the annual electricity demand in 2012 of the associated region which can be found in Table 5 on page 27. Traded volumes include exchange traded contracts as well as OTC cleared contract through exchange affiliated clearinghouses. Due to limited data availability a more precise breakdown of volumes cannot be provided for most exchanges. However, data for the Nordic market states that the share of OTC cleared volume over the past decade amounted to a constant value of 40 percent. In de German-Austrian market area the OTC clearing share decreased from about 75 percent in 2007 to also about 40 percent in 2013 and remained at this level until 2016. However regarding OTC traded volume which was not cleared over an exchange, no statement can be made since most of these volumes are not recorded or published.

As illustrated in Figure 5.11, traded future volumes show a high range of liquidity between different market regions. Highest liquidly can be found in the German and Nordic future markets. The Nordic future market is operated by NASDAQ and volume shows a decreasing trend over the past decade with a maximum of nearly 7 times of the final consumption. The German/Austrian market zone is operated by EEX and NASDAQ and volumes show a steadily growing trend. Since 2015 the German future market liquidity is the highest in Europe. Slightly lower but also still increasing liquidity can be found on the Italian market which is operated by several different platforms. In this analysis IDEX by Borsa Italiana, EEX and the MTE+PCE platforms by Gestore dei Mercati Energetici were taken into account. About 80 percent of the Italian future traded volume consisted of OTC registrations by PCE until 2014. Since EEX launched future trading on the Italian market area, volumes then shifted away from other platforms and in 2016 EEX already carried out about 60 percent of the registered volumes.

An exceptional trend can be observed on the French future market operated by the EEX. Traded volume stagnated at a very low level and then suddenly increased remarkably between 2014 and 2016 however remaining at a low level compared to the European average. The low level of exchange traded volume is a result of a high share of bilateral OTC trading and a French market mechanism called ARENH. The mechanism was designed to provide alternative suppliers access to nuclear production at a regulated price. This consequently had a negative impact on market liquidly as ARENH volumes are traded bilateral. After 2014, a planned tariff increase and wholesale prices below the existing tariff shifted the market [70]. On the Iberian market area exchange trading takes place on OMIP and in 2014 EEX entered into competition. Future market liquidity is pretty low but remarkably increased in 2016 whereas EEX already carried out 70 percent of the exchange traded future volume. Along with the Nordic market also volumes on the Czech future market slightly decreased over the past decade.

The development of future volumes show mostly increasing shares in the last years, however no uniform trend can be observed in contrast to the day-ahead and intraday markets. Traded volumes are primarily driven by regional market peculiarities.

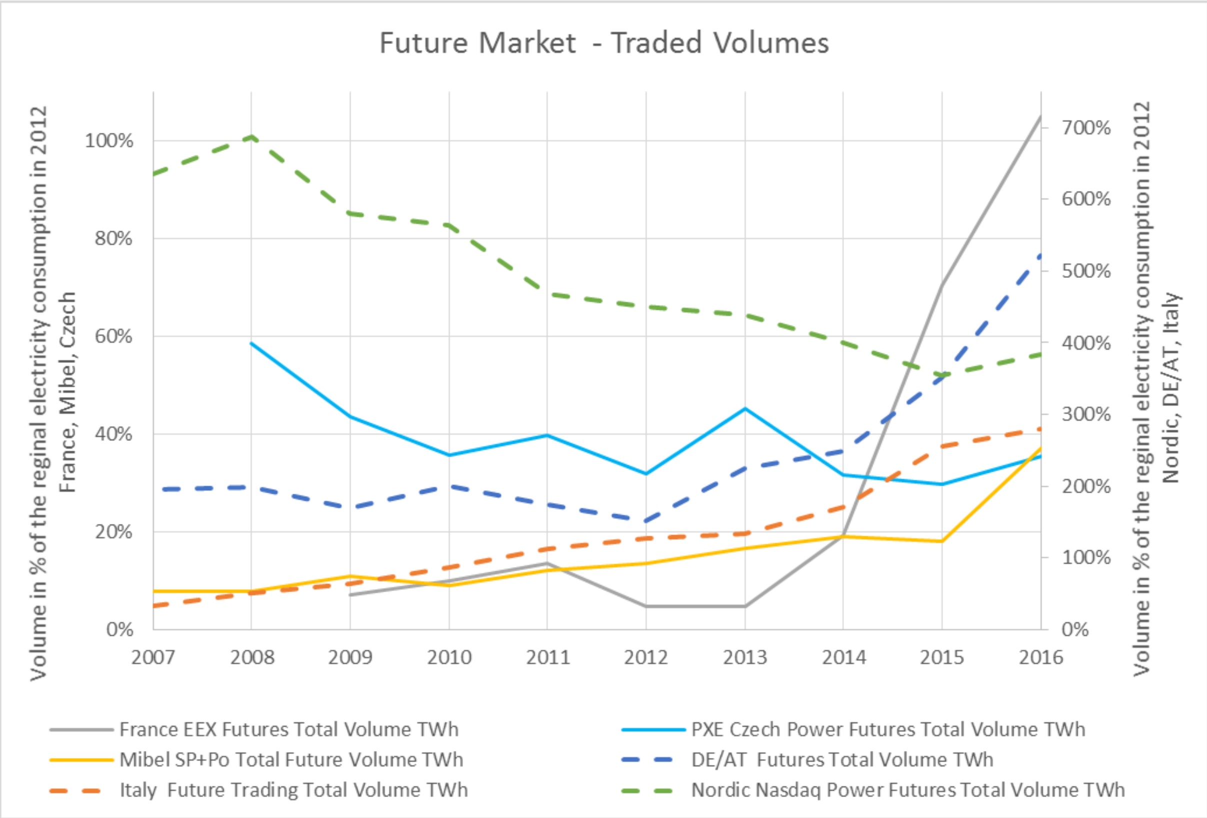

Figure 5.11: Annual Future Market Volumes in Europe

5.5 Intraday Markets

Due to no available market data, no information regarding price development on intraday markets could be recovered. However, looking at traded volumes a uniform and remarkable growing trend is observable with exception of the Iberian market area. In Figure 5.12 the development of annual intraday volumes are illustrated. Again, traded volumes are set in relation to the annual electricity demand in 2012 of the associated region which can be found in Table 5 on page 27 to provide better comparability.

The Iberian market represents the most liquid intraday market in Europe over the past decade with a traded volume maximum of 18 percent of the total demand. Until 2012 volumes got boosted by a remarkably increasing share of wind power capacity. After 2012 traded volume then decreased to the levels of 2009, but nevertheless remains the most liquid intraday market in Europe. One possible reason for this trend change is the adoption of an electricity reform in July 2013 by Spanish authorities, however this hypothesis is not verified. Also very liquid intraday markets are operated in Italy and in the German-Austrian region. Intraday volumes show a strong growing trend reaching about 10 and 7 percent of the annual consumption. The Italian intraday volume shows significant increase between 2009 and 2012, where a drastic increase of photovoltaic power plants took place. Less liquidity but also a strong growing trend can be found on the Nordic, French and Czech intraday markets with a maximum of about 1 percent of the annual electricity demand.

A significant correlation between intraday market liquidity and the installed electricity generation capacities from wind and photovoltaic can be drawn. Germany, Italy and the Iberian market region show the highest shares of variable renewables and consequently the traded volumes on the intraday volumes are much higher than in other European regions.

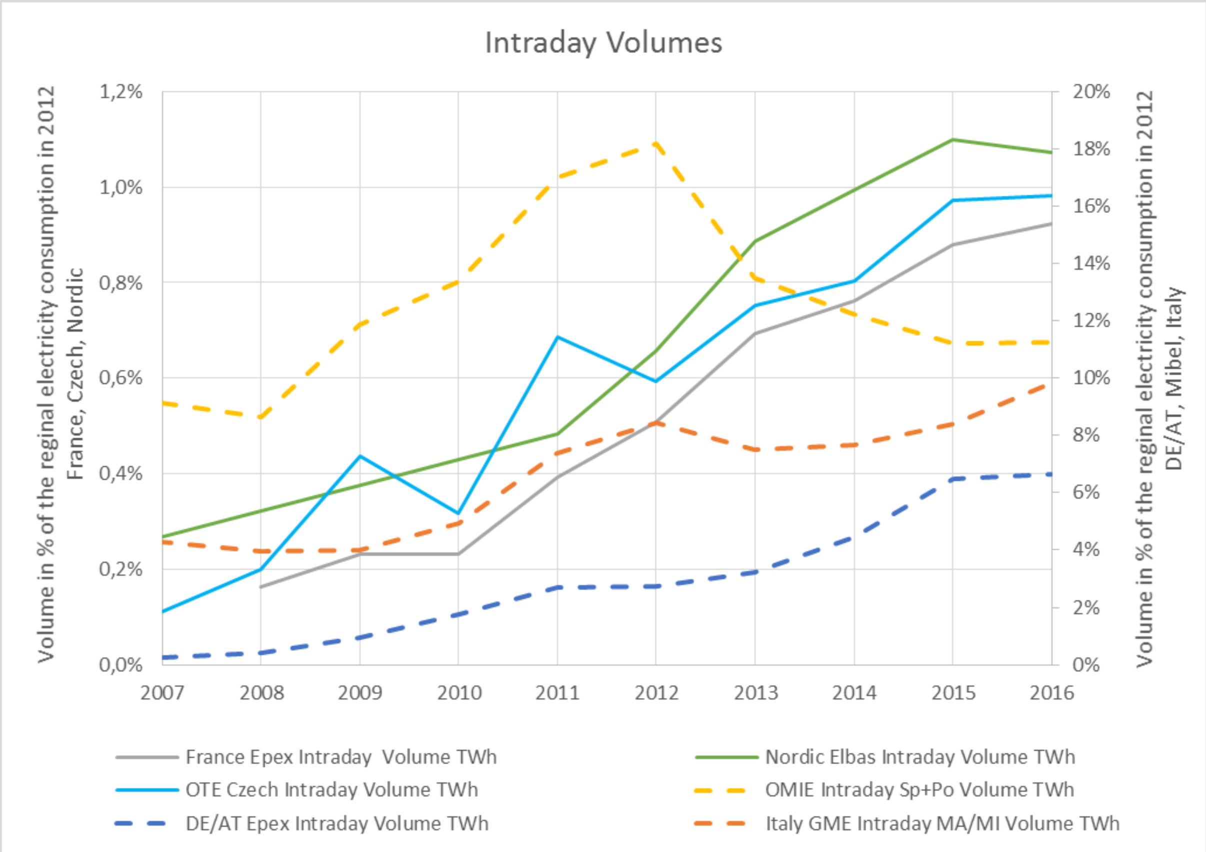

Figure 5.12: Annual Intraday Volumes in Europe

5.6 Market Structure Shifts

5.6.1 Relative Volume Developments

While the development of total traded volumes on each market segment was presented and compared in the chapters from 5.3 to 5.5, this chapter focuses on the regional trends of market development to observe possible shifts in market structures over the past decade. For this purpose in the Figure 5.13 to Figure 5.18 annual traded volumes of each market segment are set in relation to the traded amount in the year 2011. Therefore the development of market shares in the years before and after 2011 can be investigated separately. The year 2011 has been chosen to receive two about equal time periods before and after. Since the illustrated diagrams show relative development of the traded volumes, very large relative changes can occur if the reference value in 2011 is low. This is particularly noticeable in the French and Spanish future markets, where comparatively small absolute changes lead to large relative increases.

Figure 5.13 shows the market development in the German-Austrian market region. It can be observed that before 2011 traded volumes on the day-ahead and especially the intraday market highly increased. From 2007 to 2011 intraday volume increased tenfold while day-ahead volume doubled. In the same period future volume slightly decreased. In the time period until 2016 the future market showed a strong growth and traded volume tripled since 2011. Also intraday volume more than doubled in the past 5 years. Day-ahead volume also increased but only about 10 percent.

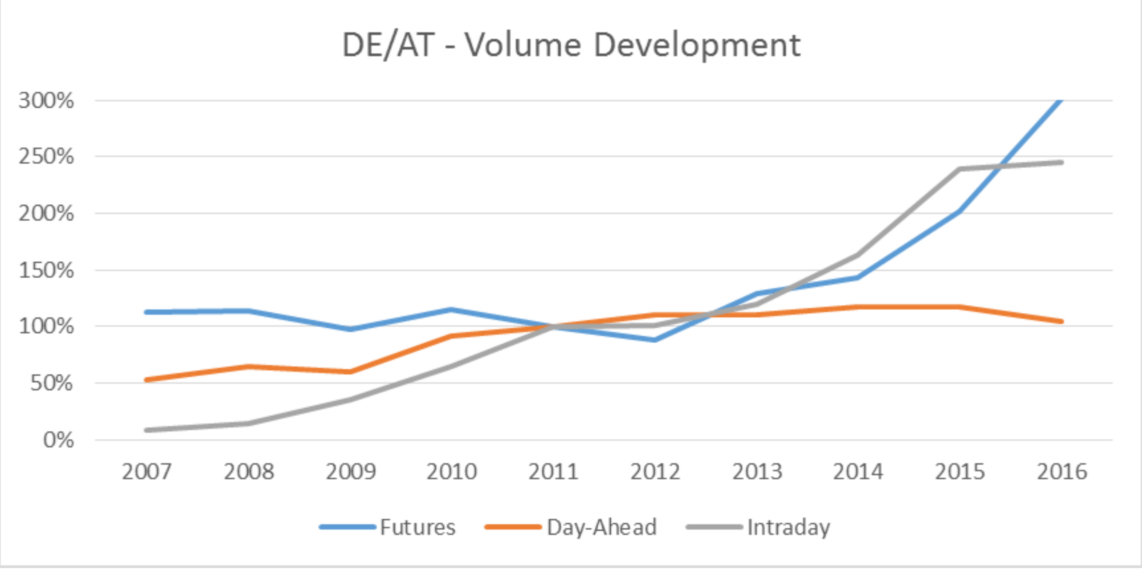

Figure 5.13: DE/AT - Volume Development

The Nordic market development is illustrated in Figure 5.14. Day-ahead volume stagnated between 2007 and 2011. At the same time intraday volume has doubled while traded volume on the future market even noticeable decreased. Until 2016 the intraday volume again more than doubled the volume from 2011. Day-ahead volume increased about 30 percent while the downward trend on the future market continued and deceased the traded volume by 20 percent.

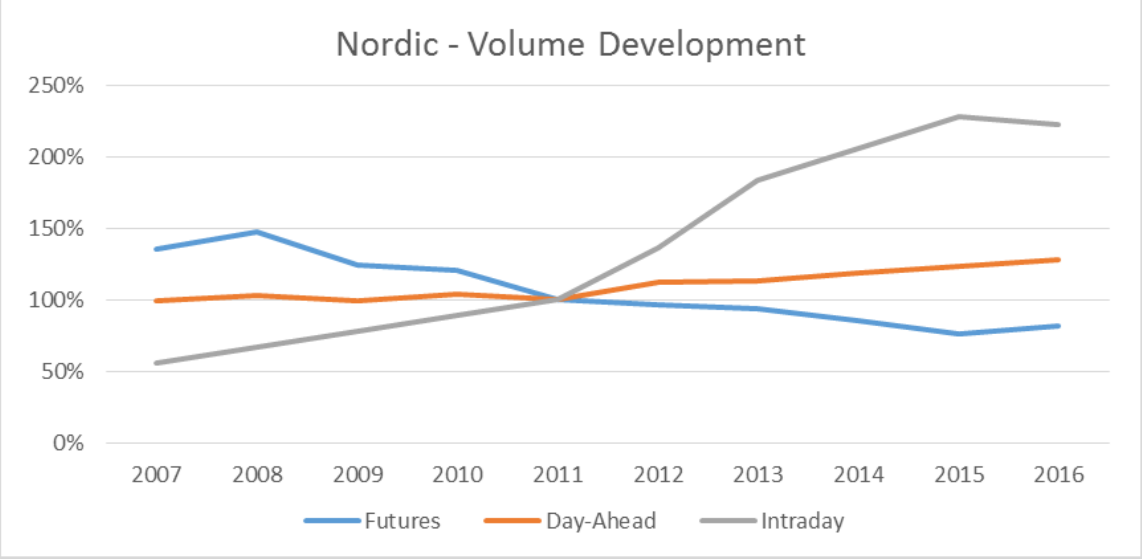

Figure 5.14: Nordic - Volume Development

In Figure 5.15 the volume development of the French market region is presented. Due to limited data availability only information starting from 2008, respectively 2009 can be analyzed. Between 2008 and 2011 day-ahead volume slightly increased by 10 percent while intraday volume has more than doubled in three years. From 2009 to 2011 also future volume doubled but remains on a low level in comparison with other countries as previously showed in Figure 5.11 on page 41. After 2011 until 2016 day-ahead volume nearly doubled while intraday volumes increased even more by about 130 percent. Future trading exploded after 2014 due to a market shift from using bilateral traded contracts according the ARENH mechanism to exchange traded futures. ARENH mechanism was designed to provide alternative suppliers access to nuclear production at a regulated price. Due to a planned tariff increase and wholesale prices below the existing ARENH tariff after 2014, it was less attractive for market participants since then. Despite the very high relative growth, the absolutely traded future volume is only roughly the same as the simple electricity consumption of the country and is therefore still significantly lower than in Germany, Italy or the Nordic market region as illustrated in Figure 5.11 on page 41.

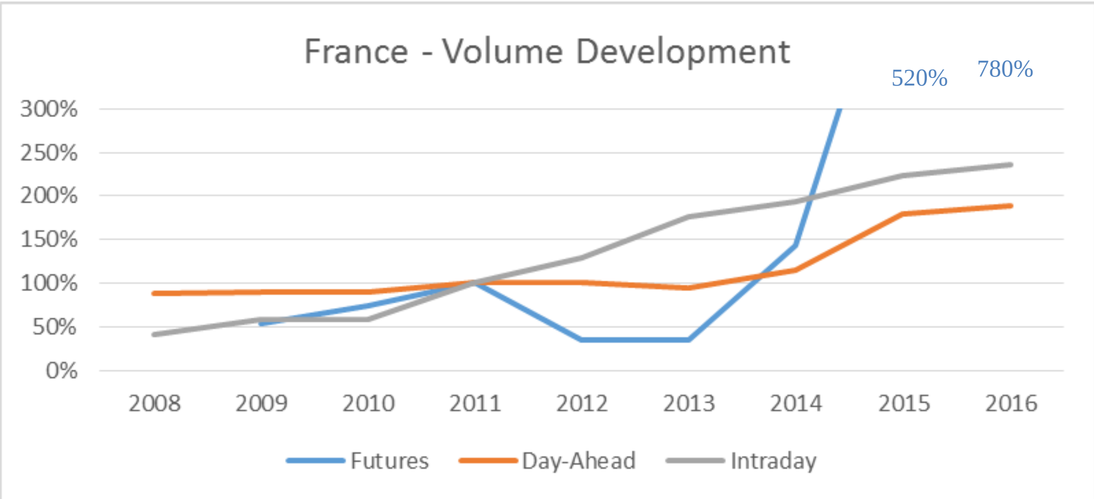

Figure 5.15: France - Volume Development

Figure 5.16 shows the development of the Italian region. Between the year 2007 and 2011 day-ahead market volume noticeable decreased by 20 percent. Parallel, traded volume on the intraday market nearly doubled and future volume more than tripled in the same period of time. After 2011 intraday volume increased by 30 percent and day-ahead also slightly grew by 10 percent until 2016. In contrast, future market volume significantly increased its volume by 250 percent between 2011 and 2016. The significant increase of intraday volume between 2009 and 2012 can be attributed to a drastic increase of installed solar power capacity.

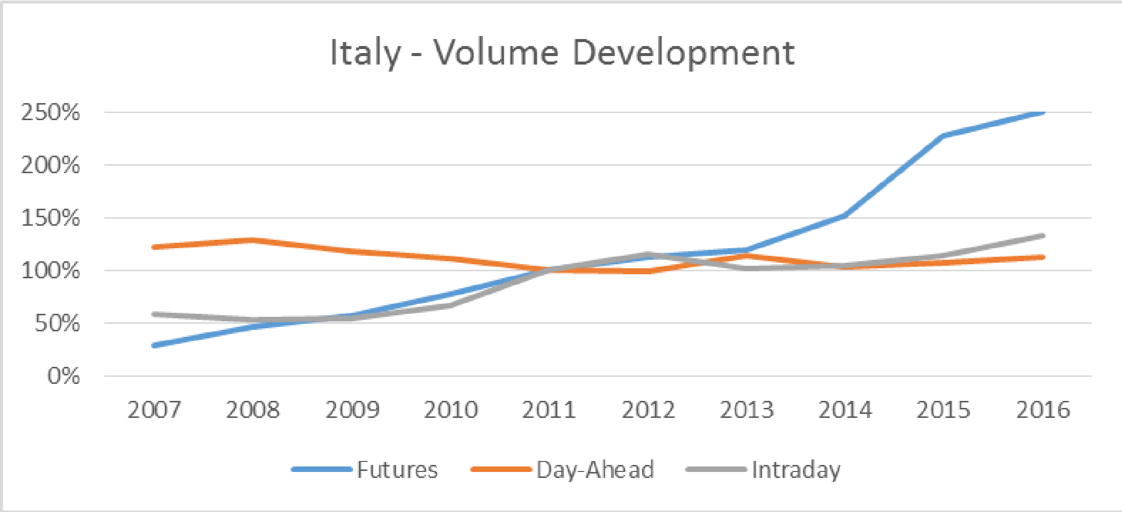

Figure 5.16: Italy - Volume Development

Market development on the Iberian area, covering Spain and Portugal, is illustrated in Figure 5.17. Same as on the Italian market region, day-ahead volume decreased by 15 percent from 2007 to 2011. Volume traded on the future market increased by 55 percent and intraday volume nearly doubled until 2011. However after 2011 the growing trend on intraday volumes stopped and started to decrease. Until 2016 the intraday volume shrunk by 35 percent. Day-ahead market volume stagnated since 2011 while future traded volume shows a strong growing trend and in 2016 already threefold the traded volume in 2011. Furthermore a clear link can be drawn between the increased intraday volume and the rising share of wind power between 2006 and 2012.

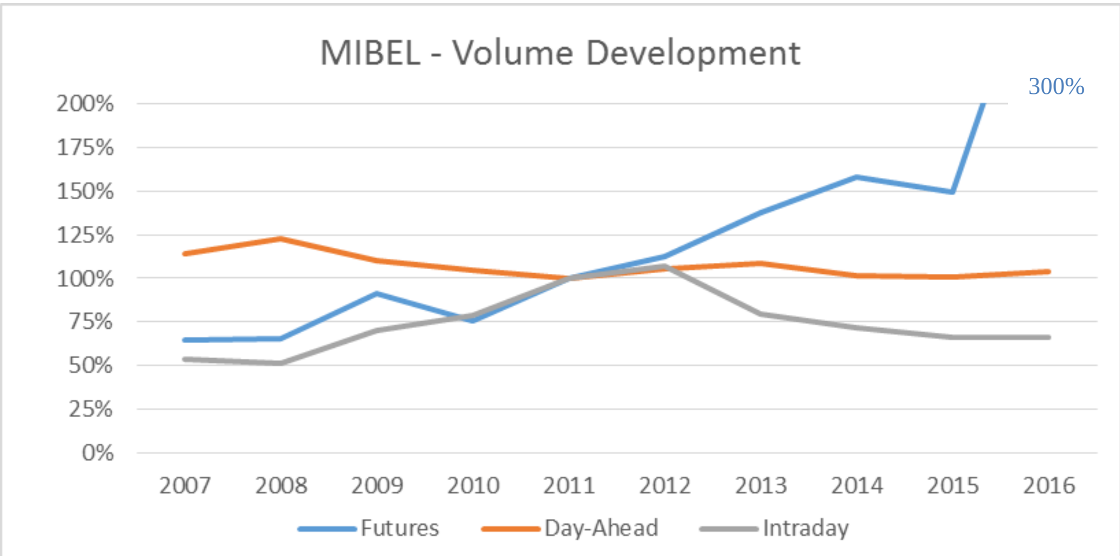

Figure 5.17: Iberian Market - Volume Development

In Figure 5.18 Czech market development is illustrated. Between 2007 and 2011 a strong growing trend on the day-ahead and intraday market can be observed. Intraday volume six-folded and day-ahead volume even ten-folded in this time period. This significant increase was accompanied by a decreasing future market volume by 30 percent. After 2011 the significant strong growing trend on the day-ahead market continued and therefore market volume again doubled until 2016. Intraday volume also grew by 40 percent in this period. The declining trend on the future market also slightly continued and market volume decreased by 10 percent until 2016.

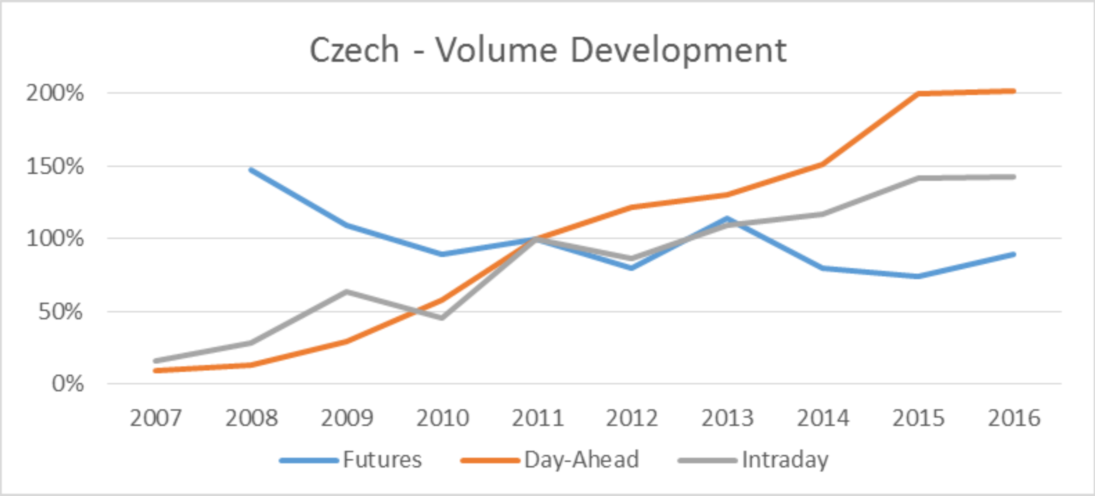

Figure 5.18: Czech - Volume Development

5.6.2 Development of Spot Market Composition

On spot markets the amount of traded and consumed electricity can only be traded once, in contrast to the future market, where it is possible that electricity is traded several times before the actual delivery and therefore is also taken several times into account. The total spot market volume consists of the traded day-ahead and intraday volumes. In this chapter the development of shares between this two market segments are analyzed. As observable in Figure 5.19, intraday volumes on different market areas move in a range between 1 to 14 percent of the total spot market volumes in 2016. Highest intraday shares can be found on the German, Italian and Iberian market, which also represent the markets with the highest shares of variable renewable electricity generation. Therefore a clear link between variable energy generation and higher share of intraday volumes can be drawn. On the Iberian market the intraday share significantly increased between 2008 and 2012 in line with increasing shares of wind capacities. After 2012 the relative share as well as the absolute traded intraday volume decreased. In Italy also a significant increase in line with photovoltaic installations can be observed in the years between 2010 and 2012. Same applies to the German market with constant rising intraday shares and variable energy capacities. Despite significant increasing volumes on the Czech intraday market the relative spot market share decreases due to an even stronger growing day-ahead market. In France the absolute traded intraday volume constantly increased until 2016, however the relative market share started to decrease in 2014.

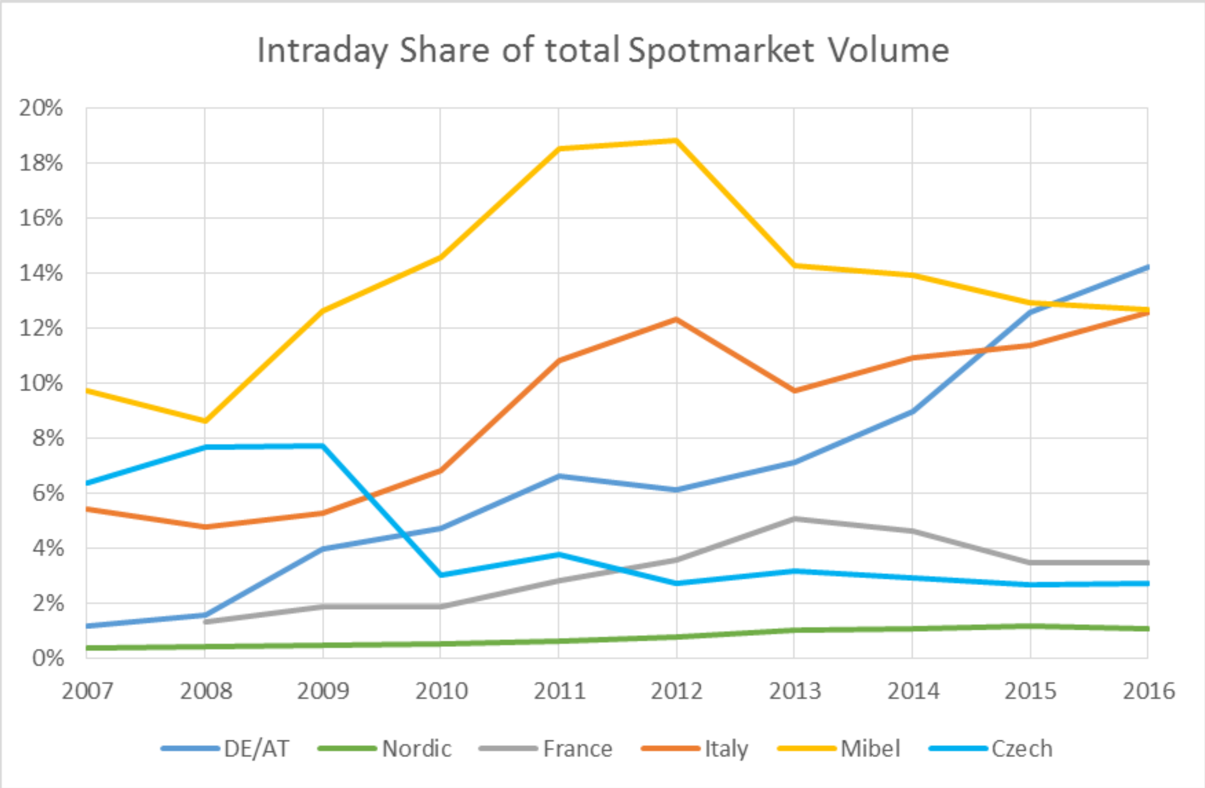

Figure 5.19: Intraday Share of total Spot Market Volume

5.7 Detail Analysis - Germany

Due to extensive data availability for the German market region further investigations on the market impact of variable renewable energy sources can be performed. Using the data presented in Table 4 on page 26, links between variable energy production and market behavior can be drawn. In this chapter the German intraday and day-ahead market are investigated to illustrate ongoing market trends caused by electricity production from wind and photovoltaic power plants. This comprises information regarding price and traded volume as well as interconnections between the day-ahead and intraday market.

Since most of the electricity from variable energy sources is traded on the spot-market, forecasted volumes from variable energy sources as well as the occurring prediction errors play an important role. The influences of an increasing share of variable renewable energy like the merit order effect or a shift in the base-peak price structure is explained in chapter 3.3.3. Since the used market data from EPEX Spot covers the German and Austrian region, slight distortions may occur because only the German wind and photovoltaic generation respectively forecast has been used in this thesis. Austrian data regarding variable renewable energy with hourly resolution could not be obtained. This note applies to all diagrams from Figure 5.20 to Figure 5.24.

5.7.1 Day-Ahead Market

Figure 5.20 states the connection between forecasted electricity volume from variable renewable energy and the traded day-ahead volume. Each dot represents one day, whereas the total year 2015 has been taken into account. Weekends and holidays which generally show less electricity demand and therefore lower day-ahead market volume has been omitted. According to the diagram a strong relationship between day-ahead volume and VRE forecast volume can be observed. Traded volume on the day-ahead market increases significantly with an increasing renewable electricity generation. Best fit of a trend line was achieved with a polynomial of second order. The applied trend line indicates that the influence on the day-ahead volume increases with a higher amount of forecasted volume from wind and photovoltaic.

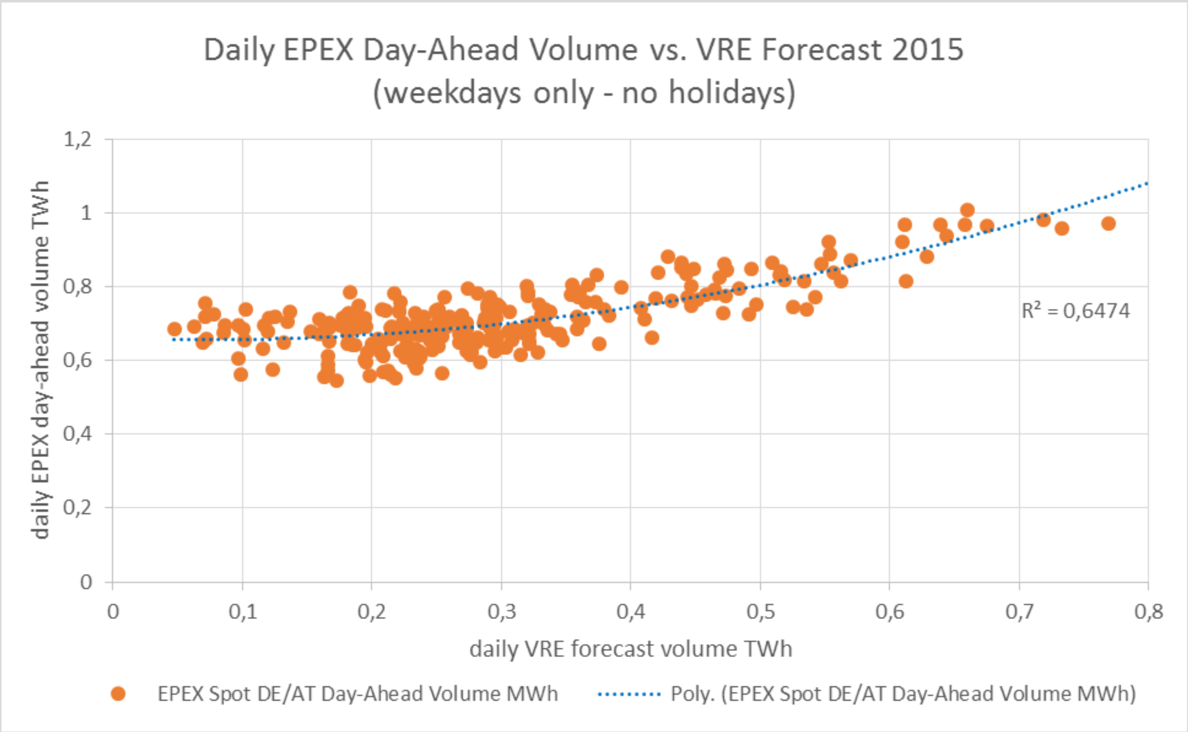

Figure 5.20: Day-ahead Volume vs. VRE Forecast 2015

In Figure 5.21 the relationship between forecasted VRE generation and the price on the day-ahead market is presented. Again the whole year 2015 without weekends and holidays have been taken into account. Due to the lower electricity demand on weekends electricity prices are lower which consequently would have distorted the observations. The diagram shows a strong price decreasing impact on the day-ahead market with an increasing VRE forecast. Best fit of a trend line was again achieved with a regressive polynomial of second order. It can be observed that with very low infeed from variable renewable energy the day-ahead price increases over proportionally. This can be attributed to the fact that with very low renewable infeed the resulting higher residual load has to be covered by thermal power plants with increasing marginal costs and the progressively increasing merit order curve. The price decreasing trend in Figure 5.21 represents a good illustration of the merit order effect.

It can be observed that the forecasted VRE volume shows a high range of variation of a daily infeed volume between 0 to 0.8 TWh, whereas the highest concentration can be found between 0.15 to 0.35 TWh per day. Converted into power values, this corresponds to an average generation of about 6 to 15 GW with a peak amount of up to 33 GW. The total installed generation capacity of wind and photovoltaic amounted to about 85 GW at the end of 2015.

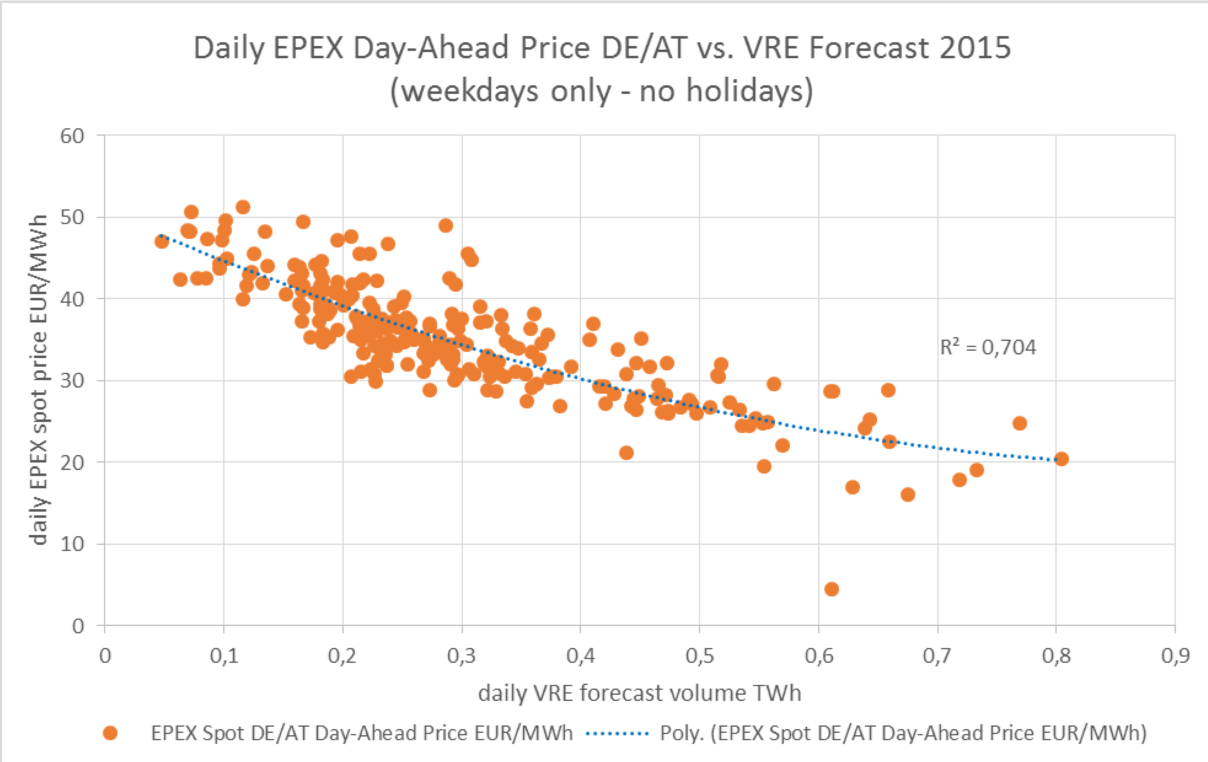

Figure 5.21: Day-ahead Price vs. VRE Forecast 2015

5.7.2 Intraday Market

In Figure 5.22 the relationship between the infeed volume of variable renewable energy and the traded volume on the intraday market is illustrated. Therefore again market data from 2015 without weekends and holiday has been taken in account. The applied linear trend line indicates slightly increased traded volume when infeed from renewable energy was higher, however due to the big spread of values, a strong relationship cannot be recognized. In contrast to the previous analyzed day-ahead market, impact of forecasted VRE infeed on the intraday market volume is relatively low.

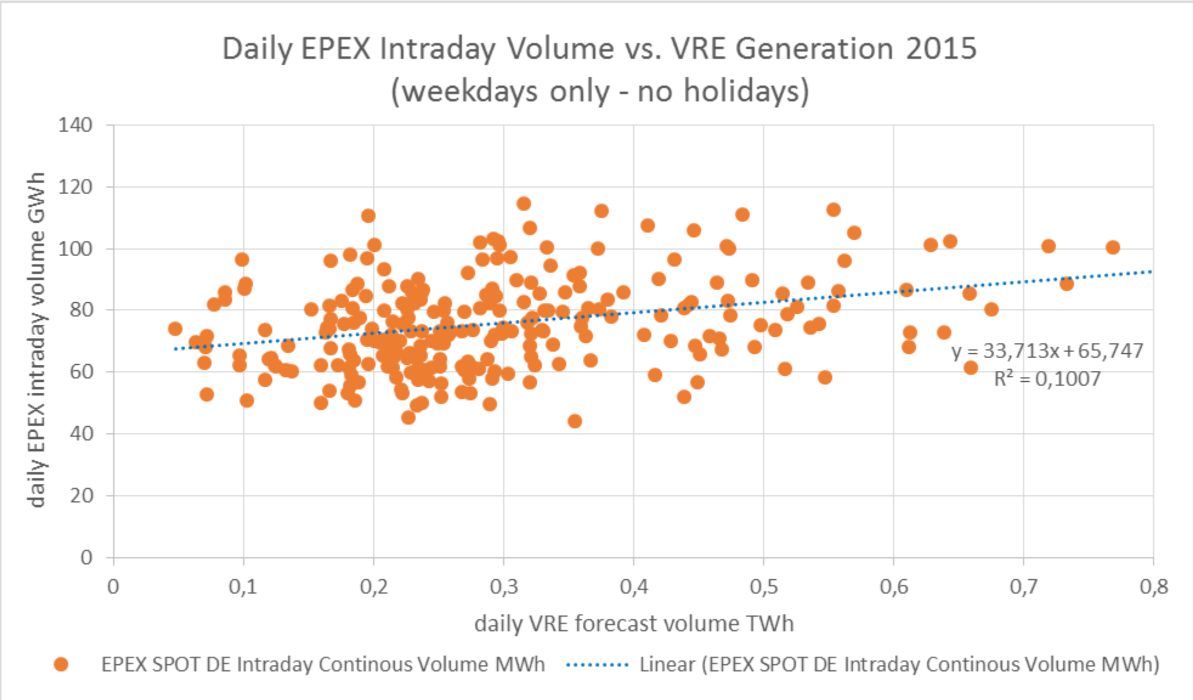

Figure 5.22: Intraday Volume vs VRE Generation 2015

Intraday trading takes place close to real time and therefore used to restore market balance as new information is obtained coming closert to the point of actual delivery. Day-ahead trading is based on forecasts and therefore unexpexted devations concerning demand and supply may occure after trades are fixed. Variable renewable energy sources by its nature show high volatility and unpredictability. Therefore intraday trading gets more and more important to react to occuring generation forecast errors resulting from an increasing share of photovoltaic and wind generation. In Figure 5.23 the relationship between the traded volume on the intraday market and the occured forecast error of variable renewable energy generation is illustraded. Therefore hourly values of the EPEX intraday market on the German and Austrian market region in April 2016 are taken into account. This time of the year shows a lot of unpredictable weather changes and consequently forecast errors here occure more often. Weekends are included in this diagram since there is no singnificant impact on the result. The absulute forecast error is calculated by summarizing the absulute values of wind end photovoltaic forecast errors as shown in formula (3).

$$E_{Abs} = |E_{Wind}| + |E_{PV}| \qquad (3)$$

Like in Figure 5.21 which uses market data from 2015, traded intraday volumes shows great dispersion, but nevertheless a strong linear relationship with the absolute forecast error can be observed. The diagram states that intraday volume on average amounts to about 2500MWh per hour if wind and photovoltaic forecasts occure without deviations. However if any infeed forecast error arises, traded intraday volume inceases nearly the same amount as the forecast deviaton. This inicates that with an rising share of variable renewable energy sources, traded amounts on the intraday markets will increase due to the proportional growth of forecast deviations.

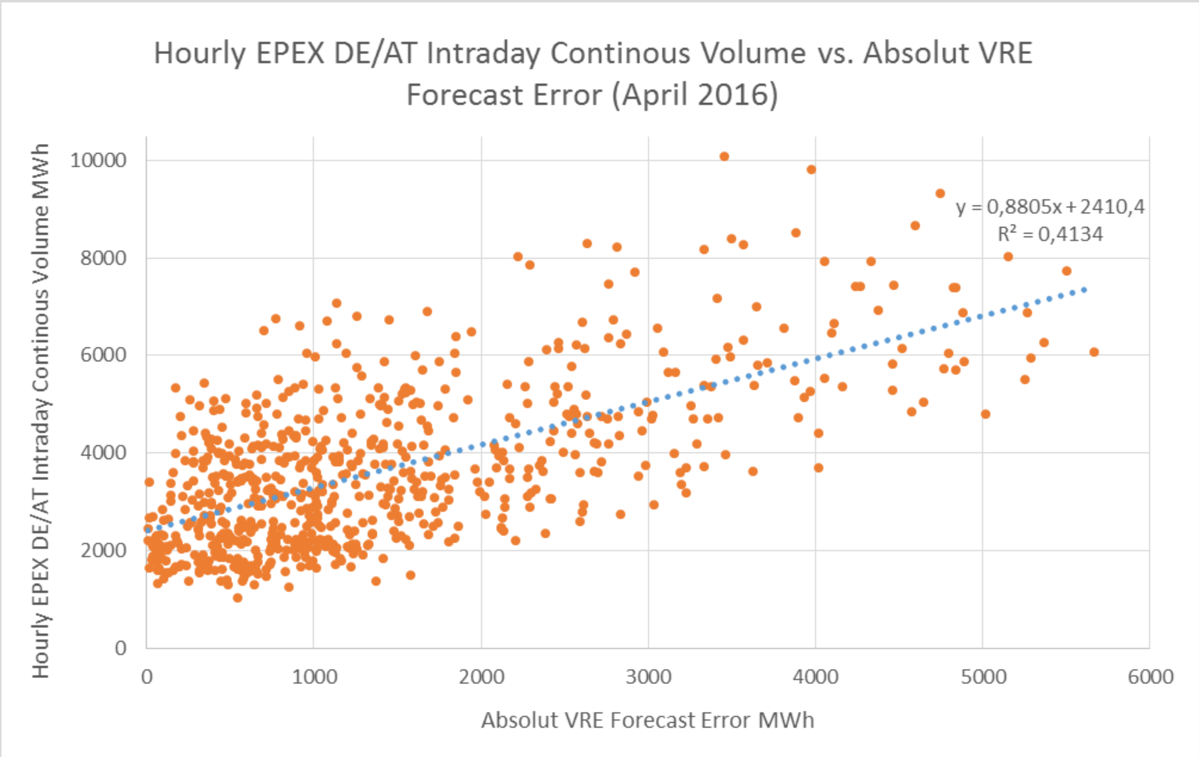

Figure 5.23: Intraday Volume vs Forecast Error - April 2016

Since prices on the intraday market are strongly connected to the day-ahead market, the absolute price development acts similar to the development of day-ahead market prices as presented in chapter 5.3.1. However the difference of the intraday price to day-ahead price is strongly influenced by variable renewably energy infeed, respectively the resulting forecast errors. Figure 5.24 shows this correlation between price difference and forecast errors. A positive price difference indicates that intraday price is higher than the day-ahead price. If the sum of forecast errors from wind and photovoltaic is positive, the actual renewable energy infeed is higher than it was forecasted on the day-ahead market. Therfore, a low amount of total forecast error can occure in two possible situations. On the one hand this can simply be the result of low forecast deviations but on the other hand a low total infeed error can also occure if for example missing wind power is covered by a surplus of photovoltaic infeed. It can be observed that negative forecast errors lead to higher intraday prices, because missing electricity has to be provided by more expensive thermal power plants. The same applies to the reverse direction where a decreasing residual load leads to declining prices. In 2016 the average infeed from variable renewables amounted to 12,6 GW whereas the absolute average total forecast error amounted to 1,16 GW which indicates an average deviation by 9 percent.

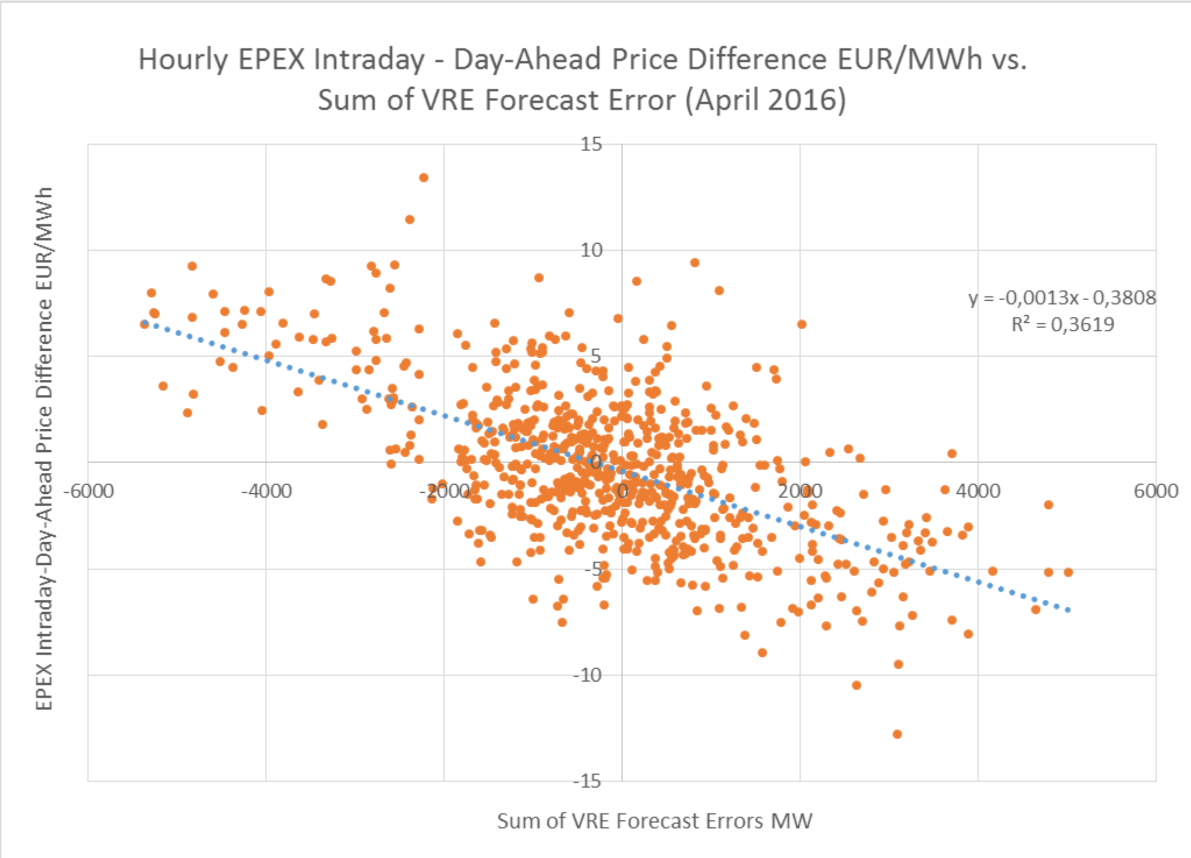

Figure 5.24: Intraday - Day-ahead Price difference vs Forecast Error

5.7.3 Volatility and Price Developments

The development of European day-ahead price volatility has already been analyzed in chapter 5.3.2 based on daily base prices of the regarding market regions. Due to the availability of hourly day-ahead price information on the German Epex-Spot exchange, a more detailed analysis can be performed. Figure 5.25 shows addtional to the daily price volatility as previously presented in Figure 5.5, the development of hourly price changes. Hourly volatility is calculated analog to formula (1) on page 32 and therefore represents the relative price change between two consecutive hours related to the 365-day price average. As observable in the diagram, the average hourly day-ahead volatility shows strong correlation to the daily averages. Furthermore the diagram shows that hourly price volatility on average is significant lower than the daily price fluctuations. A growing trend regarding the increasing share of variable renewabe electricity cannot be determined.

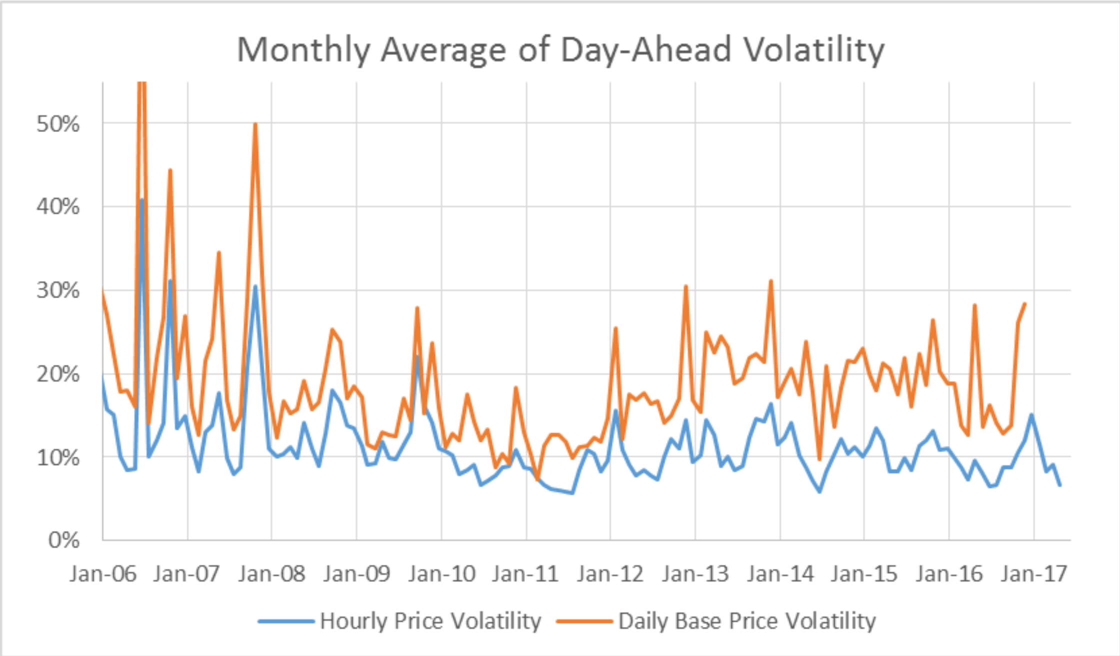

Figure 5.25: Monthly average of Spot-Price Volatility in Germany

Figure 5.26 shows the development of the average price difference between the intraday and the day-ahead market in Germany between 2007 and 2017. It can be observed that the monthly average price difference is very fluctuating. When applying a linear trendline it can be found that intraday prices on average are minimal higher than on the day-ahead market, however a slightly decreasing trend is observable.

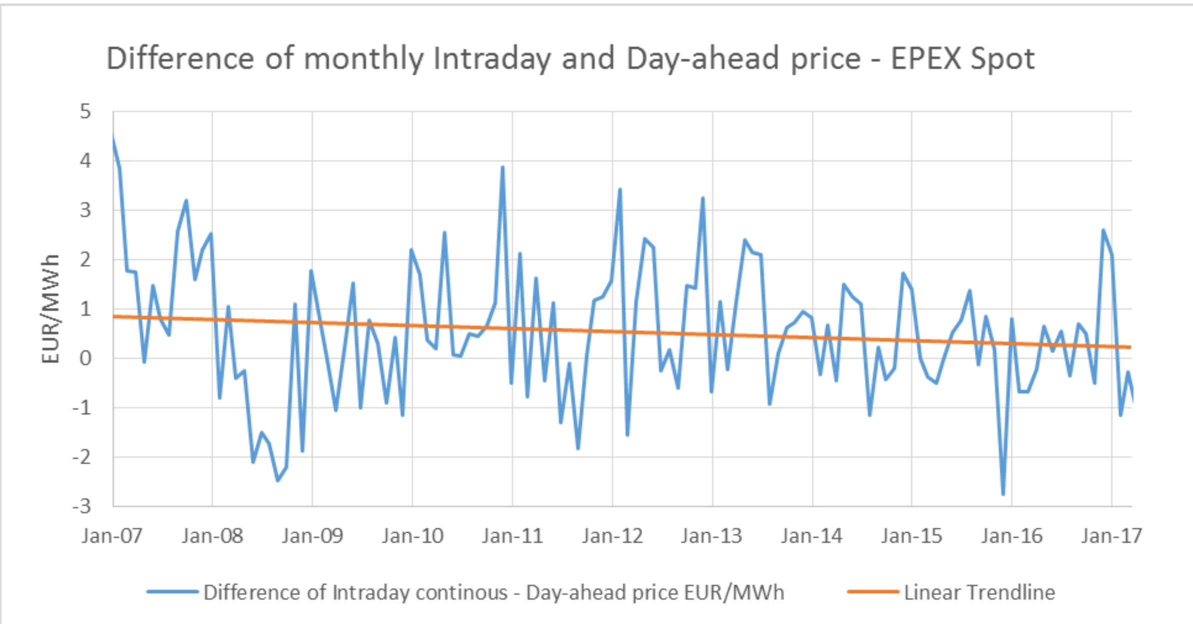

Figure 5.26: Difference of Intraday and Day-ahead price - EPEX DE/AT

In Figure 5.27 the development of the absolute price difference between day-ahead market and intraday market is illustrated. In particular, the shown values represent the monthly averages of the absolute daily price differences. This indicates how far the intraday price differs from the day-ahead price. As observable in the diagram the price difference keeps the same level and volatility over the whole period, however a negligible declining trend can be found.

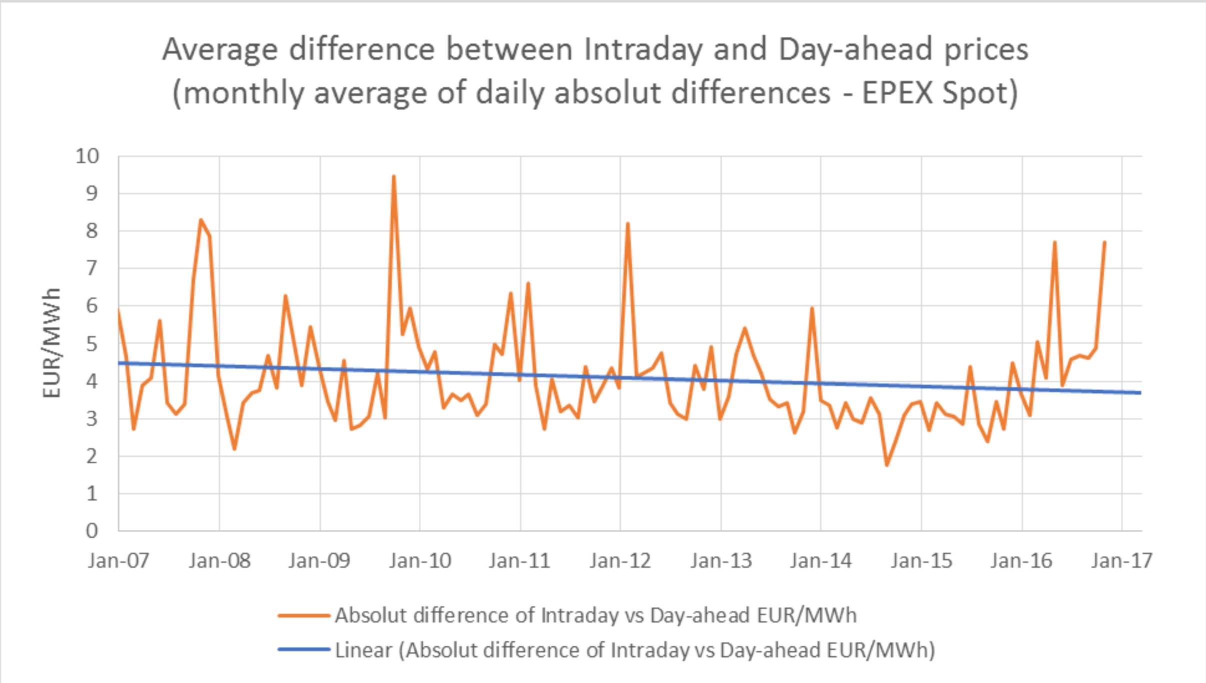

Figure 5.27: Absolute difference between Day-ahead and Intraday price

5.7.4 Breakdown of Traded Volumes

In Figure 5.28 the development of the German intraday market is presented. Until 2012, trading was settled only using 60 min contracts. Modeling steep production ramps as they occur by electricity generation using photovoltaic power was not possible sufficiently accurate. Therefore, in December 2011 15min blocks were introduced to the continuous intraday trading on the German market. In December 2014, the 15-minute auction was launched on the German intraday market to provide a reliable price signal for these blocks. The auction, which takes place daily after the day-ahead market is used to adapt production portfolios and ramps on a 15-minute basis, thereby also promoting system stability [23]. 15-minute auction trading in 2016 on average covered about 12 percent of the total intraday volume. 15-minute continuous trading amounted to 9 percent and the remaining 79 percent were attributed to the 60-minute continuous trading.

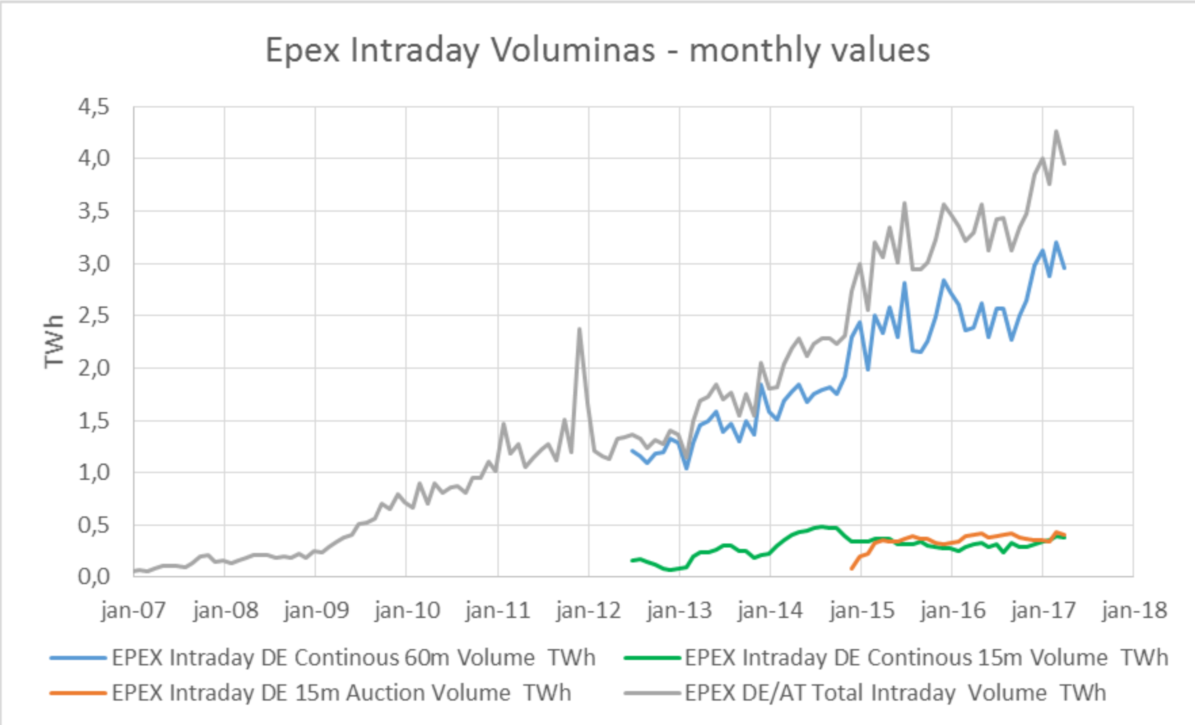

Figure 5.28: Development of German Intraday Volume

Figure 5.29 states the annual future market composition on the German and Austrian area. Due to limited data availability only years starting from 2012 can be observed. Future market volume largely consists of year-contracts which on average account for 70 percent of the future traded volumes. Quarter-contracts on average amount to 20 percent and monthly contracts only for about 10 percent. Week- and day-contracts are only traded in negligible amounts. As show in the diagram, the development of future market composition shows no clear trend which implies a relatively equal volume incensement for all types of contracts over the observed period.

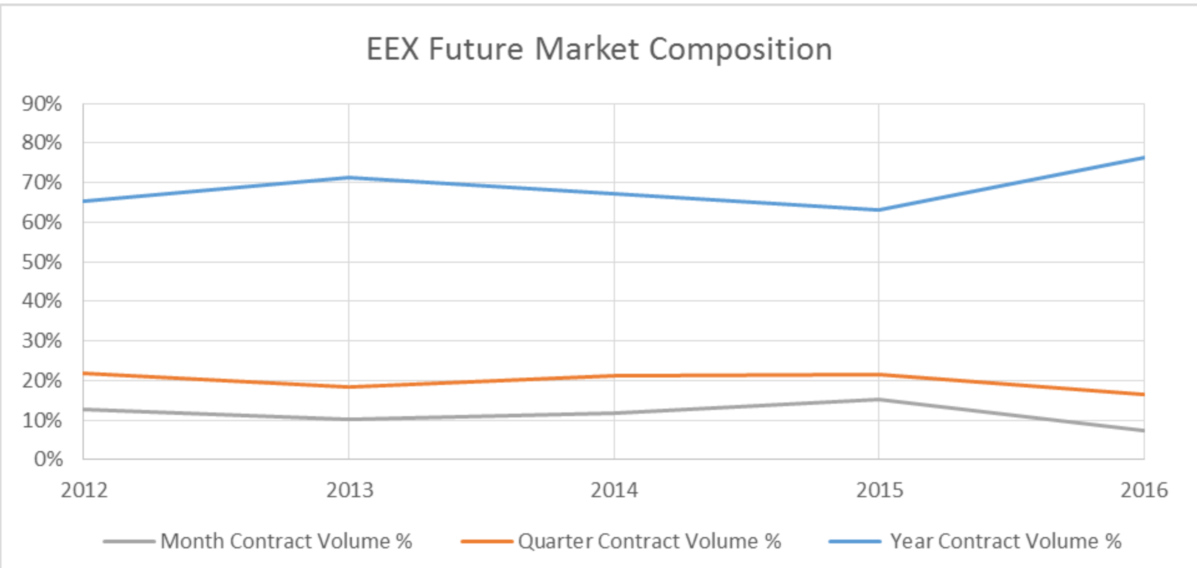

Figure 5.29: EEX Future Market Composition

6 Conclusion

6.1 Summary

Research question of this thesis was to analyze the development of the main electricity wholesale markets in Central Western Europe over the past ten years regarding an increasing share of variable renewably energy generation like wind and photovoltaic. Main task was to identify possible trends on the intraday, day-ahead and future market in consideration of price and volume structures. Therefore time series regarding market information were collected and formed to a uniform data base. This was necessary to provide comparable values since in most regions different electricity exchanges are in competition to each other and often provide only spare market data in different forms and qualities. Observed regions are the German/Austrian, French, Italian, Nordic and Iberian markets. Depending on the availability of regarding market data, time series in different resolutions from hourly up to annual market information has been created. Market information is then analyzed presented in different diagrams, illustrating the various developments regarding electricity trading. Mayor difficulties were the limited availability of market data which is being provided by electricity exchanges, as well as hardly existing data regarding over-the-counter trading.

Looking at installed shares of various technologies which are used for electricity generation, the observed market regions show significantly different power plant compositions [71]. Furthermore the development of variable renewables like wind and photovoltaic differ greatly between the observed countries, caused by divergent political decisions and applied renewable support schemes. Germany is a pioneer in this area resulting from the concluded nuclear power phase-out, and therefore contributes to a large part of the total European renewable capacities. Furthermore Italy takes a leading role regarding solar power as well as the Iberian market area in terms of wind power generation. The Nordic region is almost exclusively equipped with hydro power while the France is mostly supplied by nuclear energy but shows a steadily increasing share of wind and solar generation.

The following sub-chapter combines and summarizes the various detailed results to provide a more precise conclusion regarding the different research questions to be elaborated in this work. As apparent, not all of the observed European market regions show uniform behavior concerning market structure changes and trends on different market segments. On the one hand significant impacts resulting from the rising shares of renewable electricity generation can be observed, but market developments are furthermore also often driven by certain regional market peculiarities.

6.2 Major Findings

Development of traded volumes

First research question to be worked on deals with the development of traded volumes on the various market segments. To provide better comparison between the observed market regions, traded volumes in this chapter are again given in percentage of the regional electricity consumption in 2012 which is stated in Table 5 on page 27. Furthermore future and spot market volumes have to be considered separately because trading principles fundamentally differ between those segments. Spot market volumes on day-ahead and intraday exchanges are only traded once and therefore exactly represent the executed electricity amounts in contrast to future market volumes. The future market is primary used as a hedging instrument and trading is mostly carried out by financial fulfilled contracts which are usually traded several times before the actual execution takes place.

On the Nordic market region the future traded volume significantly decreased over the past decade from about 700 to values below 400 percent of the region's electricity consumption. Day-ahead volumes in contrast increased from 75 to nearly 98 percent and intraday volumes from 0.25 to 1.1 percent. The Nordic region only shows a minor share of variable renewables and intraday volumes therefore are lower than on other European markets, future and day-ahead liquidity however is very high as shown in Figure 5.11. The German market in contrast shows the most increasing share of renewable energy. Intraday volume rose from 0.25 to nearly 7 percent of the country's electricity demand while the day-ahead volume doubled from 20 to 45 percent. German future volumes rose from 200 up to 500 percent and therefore shows the highest liquidity in Europe. Spain has high and until 2012 increasing share of wind generation capacity and until 2012 shows the most liquid intraday market in Europe as observable in Figure 5.12. Intraday volume increased until 2012 from 10 to 18 percent but then fell to about 11 percent in 2016. Day-ahead volumes slightly decreased from 85 to 75 percent while future traded volume rose from 8 to 37 percent of the Iberian consumption. Italy has a high share of photovoltaic which was mainly installed between 2010 and 2013. In this years the intraday volume remarkably increased from 4 to 8 percent of the total Italian electricity demand. Day-ahead volumes similar to Spain slightly decreased from 75 to 65 percent while future traded volume increased from 50 to nearly 300 percent.

Summarizing it can be stated that that there is a significant connection between higher shares of variable renewable generation and rising intraday market volumes. Intraday volumes are strongly increasing on all European market regions with the only exception of the Spanish market where intraday volume started to decrease from 2013 when investments in renewable generation were drastically reduced. Day-ahead volumes show also steadily increasing amounts with the exception of the Spanish and Italian regions which suffered a weaker economic situation. Future traded volumes are mainly driven by market peculiarities but however also show mostly increasing volumes. The Nordic market here is an exception with constantly decreasing volumes over the past decade.

Trends for changes in market shares

The second research question deals with the development of market shares. Since future traded volumes are counted several times before the actual execution and are not in direct connection to the spot volumes, mainly interesting are the shares of intraday and day-ahead volumes. As previously presented, the development of intraday shares of total spot market volumes can be found in Figure 5.19 on page 47. The different observed market regions show different market developments and so no uniform trend regarding spot market shares can be applied. However a significant connection between higher shares of variable renewably generation and a therefore higher share of intraday volumes can be observed.

On the German market the share of intraday volumes steadily increased in line with the rising share of variable renewable energy capacities from 1 to 14 percent of the total spot volume between 2007 and 2016. Also the intraday share on the Iberian region in line with wind generation capacities increased from 10 to 18 percent until 2012, but then decreased down to 13 percent due to a decreasing intraday volume after a drastic reduction of renewable support schemes in 2013. Similar development can be found on the Italian market region. The share of intraday trading until 2012 increased in line with significant photovoltaic installations from 5 to 12 percent. In 2013 the intraday share slightly dropped due to a high day-ahead volume but overall remained at about the level from 2012 when the installation of additional renewable capacities has been stopped. Also on the French market the share of intraday trading slightly increased in line with renewable capacities from 1 to 4 percent but remains low in comparison to the other European regions. With a constant 1 percent of the however remarkably increasing total spot market volume over the past decade, the Nordic intraday share stands the lowest in Europe. The Czech intraday share decreased from 7 to 3 percent in 2010 but then remained at a constant level until 2016 despite an overall increasing amount of absolute intraday volume over the whole decade.

Price structure changes

The third research question of this theses deals with the changes in price structures over the past decade. Price development on the different European spot exchanges has been analyzed in chapters 5.3.1 to 5.3.4 starting on page 30. As stated, spot prices are primarily dependent on underlying fundamentals regarding supply and demand. Until 2012 the overall price development was determined by high commodity prices at the beginning, followed by the financial crisis and slow recovery of the economic situation. Since 2012 electricity wholesale prices are steadily decreasing which is caused to a great extent by the merit order effect of steadily increasing shares of variable renewable energy generation and resulting overcapacities on the supply side. Prices on the German day-ahead market for example decreased from about 50 to 30 €/MWh over the past five years. Also in Italy a drastic price reduction from 80 to 50 €/MWh is observable since 2012. The price reducing effect of higher infeed from renewable electricity with nearly zero marginal generation costs is clearly recognizable in Figure 5.21 on page 49, which analyzes the German day-ahead prices in 2015. On future markets a reduction of risk premiums is observable over the past five years as shown more detailed in Figure 5.10 on page 39.

Furthermore a price converging and harmonizing effect resulting from coupling different market zones can be observed. The development of market coupling is stated more detailed in chapter 3.1.2 on page 10. Available cross-boarder capacities are efficiently used to balance electricity supply, especially during bottleneck situations in times with extraordinary high or low infeed from renewable energies and consequently reduce the occurrence of price peaks. In chapter 5.3.2 the volatility development of daily spot prices in Europe has been analyzed. Highest price volatility can be found on the German market with an average price difference of 20 percent between two calendar days. In contrast, the average volatility on the Nordic region only amounts to 5 percent, resulting from electricity generation by almost exclusively hydro and nuclear power. Volatility levels on all observed market regions remained stable over the past decade and therefore no volatility increase can be observed by the rising shares of variable renewable electricity generation. This also applies to the volatility development of hourly spot prices as analyzed on the German market in Figure 5.25 on page 53.

A change in the electricity price structure regarding base and peak prices can also be determined as a result of increasing photovoltaic generation in Italy and Germany. This effect has been analyzed more detailed in chapter 5.3.3. Resulting from a high share of thermal power plants, the difference between peak and base prices in 2006 on average amounted to 10 €/MWh in Germany and 20 €/MWh in Italy. Due to remarkable photovoltaic installations this price difference significantly decreased to nearly zero until 2012. Since then base-peak differences also show strong annually patterns as a consequence of the higher solar radiation in summer, which furthermore often even leads to base-peak price inversions. In contrast, the Nordic market region shows constant low base-peak price differences of about 5 €/MWh over the whole decade as a consequence of electricity generation mostly based on hydro power.

6.3 Conclusion and Further Outlook

Electricity market structures go through a constant adaptive process reacting to the given market conditions which are also constantly changing. The past decade was marked by a shift away from conventional electricity generation towards increasing shares of variable renewable energy sources like wind and photovoltaic. The zero marginal generation costs of renewables as well as an increased level of overcapacity on the supply side leads to declining electricity prices on the spot and future markets as well as to changing base-peak price structures. Furthermore it can be stated that a rising share of variable renewable energy leads to an increased spot market volumes and a shift towards short-term intraday trading. Future traded volumes are more dependent of regional market peculiarities and development differs between the European markets. Due to difficult feed-in predictions, there is a growing need for the possibility to react to new information until short before the actual point of delivery. In line with the rising shares of variable renewables, also the electricity amounts resulting from prediction errors which have to be compensated on intraday markets are increasing. Steep power gradients which occur mostly by photovoltaic generation additionally require the possibility to model steep load profiles. This is realized by the introduction of 15-minute contracts on the intraday market on several European electricity exchanges. Unfavorable characteristics of variable renewables like the volatile electricity generation and occurring bottleneck situation with extreme prices are softened by increased cross boarder trading and the introduction of day-ahead market coupling, which furthermore also harmonizes electricity prices between the various European market regions.

It is highly probable that the share of renewable energy in Europe and especially in Germany will continue to increase significantly in the future, however this is primary dependent on policy decisions and adaption of renewable support schemes. Due to the preferable generation from wind and photovoltaics, which is determined by no fuel requirement and therefore nearly zero marginal costs and no emissions, conventional plants are slowly getting displaced from the merit order and only act as backup plants to provide system stability in periods of low renewable availability. With decreasing electricity wholesale prices also financial incentives for investments in new generation capacities are declining which has to be considered. With higher shares of variable renewables, trading on spot exchanges and especially intraday trading will get more important. In order to be able to compensate larger infeed fluctuations, it will be necessary to increase cross-boarder capacities for more effective market coupling as well as to reduce the possible occurrence of bottleneck situations. In a further step also the coupling of intraday markets can contribute for a more efficient integration of variable renewable generation as long as there is no sufficiently advanced technology to store electricity in an economical way.

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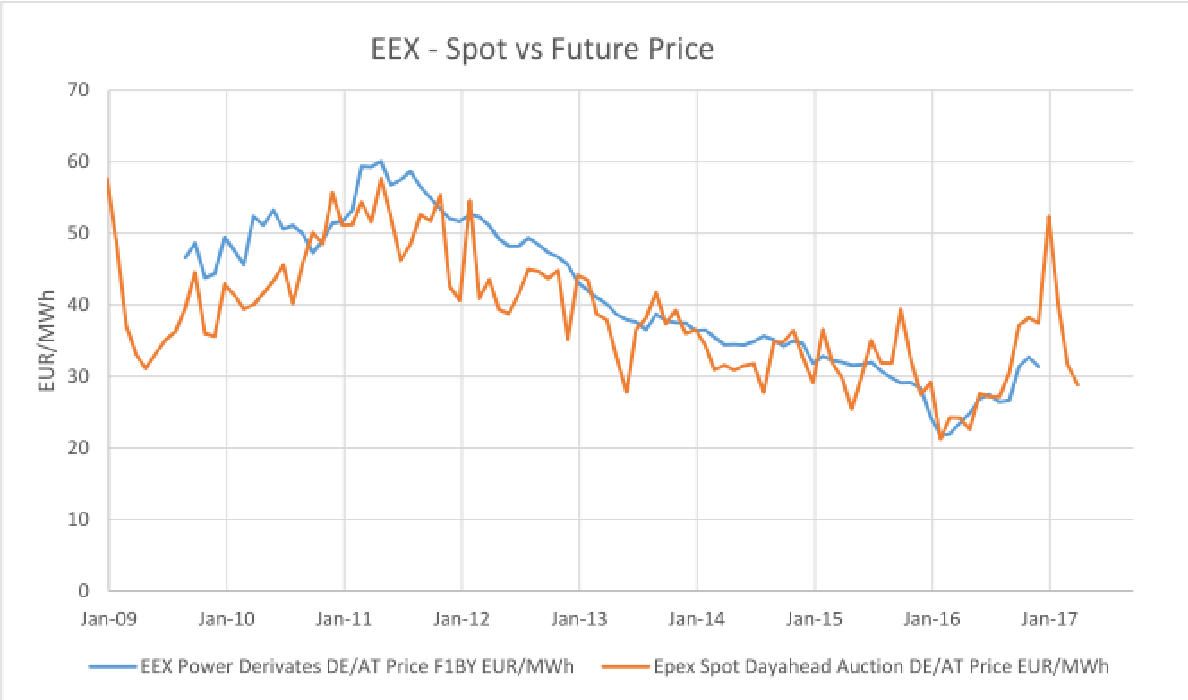
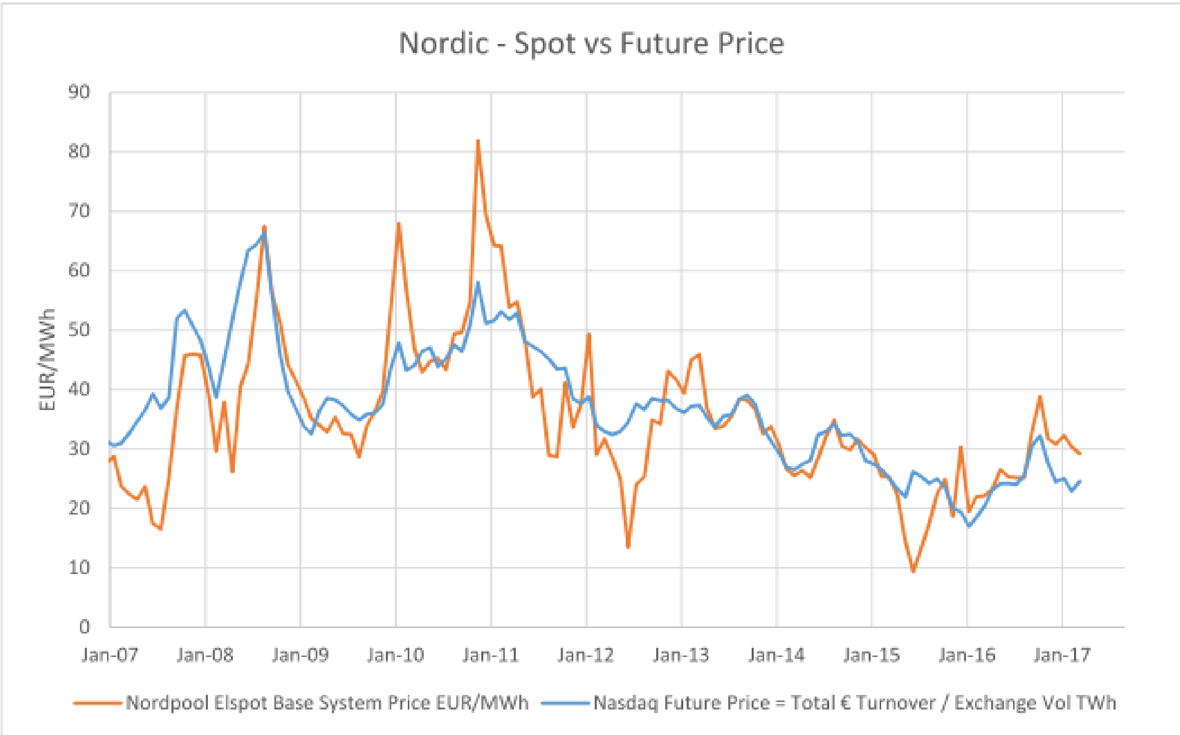
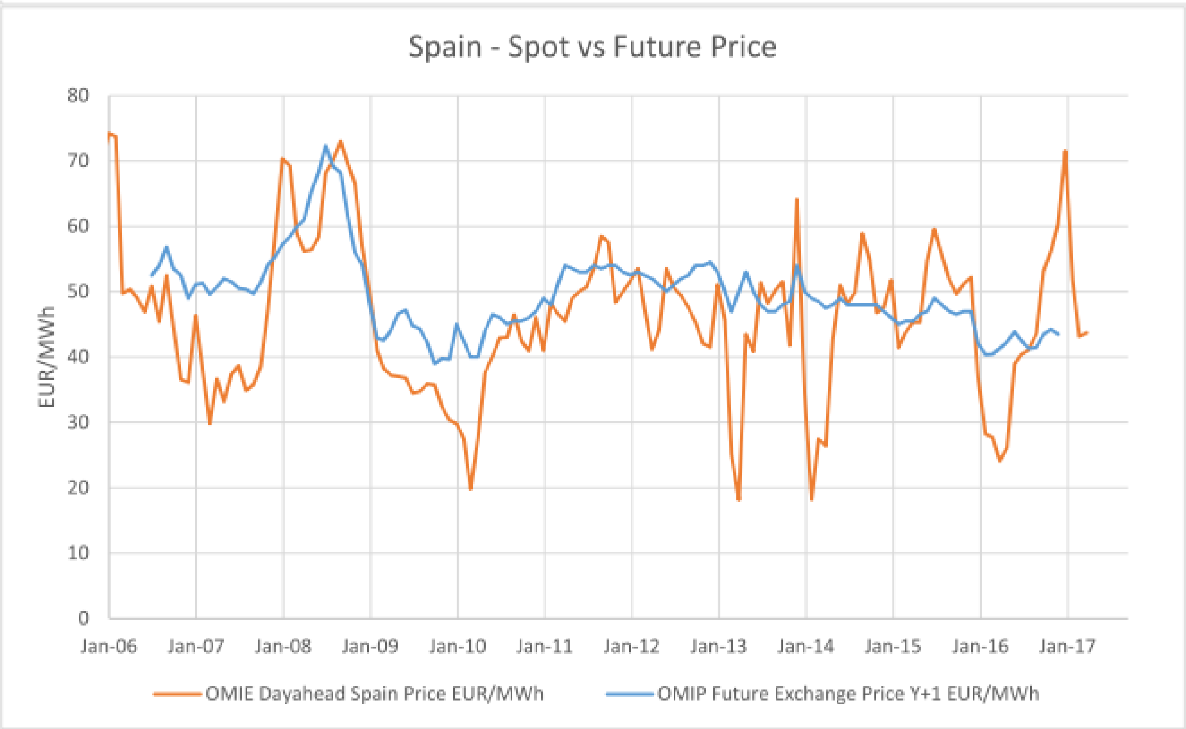
10 Appendix

Following diagrams show the development of spot and future prices in different market regions. Future prices in the diagram represent the monthly average trading price of front-year base contracts while spot market prices correspond to monthly average day-ahead prices.






Spain - Spot vs Future Price
80
70
60
50
40
30
20
10
0
EUR/MWh
Jan-06
Jan-07
Jan-08
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15
Jan-16
Jan-17
OMIE Dayahead Spain Price EUR/MWh
OMIP Future Exchange Price Y+1 EUR/MWh